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PRINCIPLES
OF
GEOLOGY:

BEING
AN INQUIRY HOW FAR THE FORMER CHANGES OF
THE EARTH'S SURFACE
ARE REFERABLE TO CAUSES NOW IN OPERATION.

BY
CHARLES LYELL, Esq. F.R.S.

FOREIGN SECRETARY TO THE GEOLOGICAL SOCIETY OF LONDON.

"Amid all the revolutions of the globe, the economy of Nature has been uniform, and her laws are the only things that have resisted the general movement. The rivers and the rocks, the seas and the continents, have been changed in all their parts; but the laws which direct those changes, and the rules to which they are subject, have remained invariably the same."

PLAYFAIR, *Illustrations of the Huttonian Theory*, § 374.

IN FOUR VOLUMES.

VOL. I.

THE THIRD EDITION.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.

1835.

EdueT 20298.35.530 v.1

AUG 13 1921

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JANUARY 25, 1924

LONDON:
Printed by A. SPOTTISWOODS,
New-Street-Square.

P R E F A C E.

IN the Preface to the former edition of the "Principles of Geology," I gave a brief account of the progress of the work up to the publication of the Third Volume in 1833. This account I shall now repeat with some omissions, and with the addition of such information as I think will be useful to the reader respecting the latest alterations made in the work.

The original MS. of the "Principles of Geology" was delivered to the publisher at the close of the year 1827, when it was proposed that it should appear in the course of the year following, in two volumes octavo. Many causes concurred to delay the completion of the work, and considerably to modify the original plan. In May, 1828, when the preliminary chapters on the History of Geology, and some others which follow them in the first volume, were nearly finished, I became anxious to visit several parts of the continent, in order to acquire more information concerning the tertiary formations. Accordingly,

I set out in May, 1828, in company with Mr Murchison, on a tour through France and the north of Italy, where we examined together many districts which are particularly described in this work. We visited Auvergne, Velay, Cantal, and the Vivarais, and afterwards the environs of Aix, in Provence, and then passed by the Maritime Alps to Savona, thence crossing to Piedmont by the Valley of the Bormida.

At Turin we found Signor Bonelli engaged in the arrangement of a large collection of tertiary shells obtained chiefly from the Italian strata; and as I had already conceived the idea of classing the different tertiary groups, by reference to the proportional number of recent species found fossil in each, I was at pains to learn what number Signor Bonelli had identified with living species, and the degree of precision with which such identifications could be made. With a view of illustrating this point, he showed us suites of shells common to the Subapennine beds and of the Mediterranean, pointing out that, in some instances, not only the ordinary type of the species, but even the different varieties had their counterparts both in the fossil and recent series. The same naturalist informed us that the fossil shells of the hill of the Superga, at Turin, differed as a group from those of Parma and other localities of the Sub-

Apennine beds of northern Italy; and, on the other hand, that the characteristic shells of the Superga agreed with the species found at Bordeaux and other parts of the South of France.

I was the more struck with this remark, as Mr. Murchison and myself had already inferred that the highly-inclined strata of the Valley of the Bormida, which agree with those of the Superga, were older than the more horizontal Subapennine marls, by which the plains of the Tanaro and the Po are skirted.

When we had explored some parts of the Vicentine together, Mr. Murchison re-crossed the Alps, while I directed my course to the south of Italy, first staying at Parma, where I studied, in the cabinets of Signor Guidotti, a beautiful collection of Italian tertiary shells, many of which had been identified with living testacea. Signor Guidotti had not examined his fossils with reference to their bearing on geological questions, but computed, on a loose estimate, that there were about 30 per cent. of living species in the Subapennine beds. I then visited Florence, Sienna, and Rome, continuing my inquiries respecting the tertiary strata as exhibited in those territories.

On my arrival at Naples I became acquainted with Signor O. G. Costa, who had examined the fossil shells of Otranto and Calabria, and had

collected many recent testacea from the seas surrounding the Calabrian coasts. His comparison of the fossil and living species had led him to a very different result in regard to the southern extremity of Italy, from that to which Signors Guidotti and Bonelli had arrived in regard to the north; for he was of opinion that few of the tertiary shells were of extinct species. In confirmation of this view, he showed me a suite of fossil shells from the territory of Otranto, in which nearly all the species were recent.

In October, 1828, I examined Ischia, and obtained from the strata of that island the fossil shells named in Appendix II. Vol. III., p. 57. of the first edition. They were all, with two or three exceptions, recognized by Signor Costa as species now inhabiting the Mediterranean; a circumstance which greatly astonished me, as I procured some of them at the height of two thousand feet above the level of the sea (Vol. III. p. 390.).

Early in November, 1828, I crossed from Naples to Messina, and immediately afterwards examined Etna, and collected on the flanks of that mountain, near Trezza, the fossil shells alluded to in the third volume (p. 335., and Appendix II., p. 53., first edition). The occurrence of shells in this locality was not unknown to the naturalists of Catania; but, having been recognized by them

as *recent* species, they were supposed to have been carried up from the sea-shore to fertilize the soil, and therefore disregarded. Their position is well known to many of the peasants of the country, by whom the fossils are called “roba di diluvio.”

In the course of my tour, I had been frequently led to reflect on the precept of Descartes, that “a philosopher should once in his life doubt every thing he had been taught;” but I still retained so much faith in my early geological creed as to feel the most lively surprise, on visiting Sortino, Pentalica, Syracuse, and other parts of the Val di Noto, at beholding a limestone of enormous thickness filled with recent shells, or sometimes with the mere casts of shells, resting on marl in which shells of Mediterranean species were imbedded in a high state of preservation. (See Book IV. Chap. VI.) All idea of attaching a high antiquity to a regularly stratified limestone, in which the casts and impressions of shells alone were discernible, vanished at once from my mind. At the same time I was struck with the identity of the associated igneous rocks of the Val di Noto with well-known varieties of “trap” in Scotland and other parts of Europe; varieties which I had also seen entering largely into the structure of Etna. I occasionally amused myself with spe-

culating on the different rate of progress which Geology might have made, had it been first cultivated with success at Catania, where the phenomena above alluded to, the great elevation of the modern tertiary beds in the Val di Noto, and the changes produced in the historical era by the Calabrian earthquakes, would have been familiarly known.

From Cape Passaro I passed on by Spaccaforno and Licata to Girgenti, where I abandoned my design of exploring the western part of Sicily, that I might return again to the Val di Noto and the neighbourhood of Etna, and verify the discoveries which I had made. With this view, I travelled by Caltanissetta, Piazza, Caltagirone, Vizzini, Militello, Palagonia, Lago Naftia, and Radusa, to Castrogiovanni, and from thence to Palermo, at which last place I procured the shells named in Appendix II., p. 55., first edition. The sections on this new route confirmed me in my first opinions respecting the Val di Noto.*

When I again reached Naples, in January, 1829, I found that Signor O. G. Costa had examined the tertiary fossils which I had sent to him from different parts of Sicily, and declared them to be for the most part of recent species. I

* See the 6th, 8th, and 9th chapters of Book IV.

then bent my course homeward, seeing, at Genoa, Professor Viviani and Dr. Sasso, the last of whom put into my hands his memoirs on the strata of Albenga (see Vol. IV. p. 16.), in which I found that, according to his list of shells, the tertiary formations at the foot of the maritime Alps contained about 50 per cent. of recent species.

I next re-visited Turin, and communicated to Signor Bonelli the result of my inquiries respecting the tertiary beds of the south of Italy, and of Sicily, upon which he kindly offered to review his fossils, some of which had been obtained from those countries, and to compare them with the Subapennine shells of northern Italy. He also promised to draw up immediately a list of the shells characteristic of the tertiary green-sand of the Superga, and common to that locality and Bordeaux, that I might publish it at the end of my second volume; but the death of this amiable and zealous naturalist soon afterwards deprived me of the benefit of his assistance.

I had now fully decided on attempting to establish four subdivisions of the great tertiary epoch, the same which are fully illustrated in the present work. I considered the basin of Paris and London to be the type of the first division; the beds of the Superga, of the second; the Subapennine strata of northern Italy, of the third;

and Ischia and the Val di Noto, of the fourth. I was also convinced that I had seen proofs, during my tour in Auvergne, Tuscany, and Sicily, of volcanic rocks contemporaneous with the sedimentary strata of three of the above periods.

On my return to Paris, in February, 1829, I communicated to M. Desnoyers some of the new views to which my examination of Sicily had led me, and my intention to attempt a classification of the different tertiary formations in chronological order, by reference to the comparative proportion of living species of shells found fossil in each. He informed me that, during my tour, he had been employed in printing the first part of his memoir, not yet published, on "the Tertiary Formations more recent than the Paris Basin," in which he had insisted on the doctrine "of the succession of tertiary formations of different ages." At the end of the first part of his memoir, which was published before I left Paris*, he annexed a note on the accordancy of many of my views with his own, and my intention of arranging the tertiary formations chronologically, according to the relative number of fossils in each group, which were identifiable with species now living.

At the same time I learned from M. Des-

* See *Ann. des Sci. Nat.*, xvi. p. 214.

noyers, that M. Deshayes had, by the mere inspection of the fossil shells in his extensive museum, convinced himself that the different tertiary formations might be arranged in a chronological series. I accordingly lost no time in seeing M. Deshayes, who explained to me the data on which he considered that three tertiary periods might be established, the two first of which corresponded to two which I was prepared to adopt (the Eocene and Miocene), and the last of which embraced the Subapennine beds, as distinguished from those of Bordeaux and the Superga. I at once perceived that the fossils obtained by me in my tour would form but an inconsiderable contribution to so great a body of zoological evidence as M. Deshayes had already in his possession. I therefore requested him to examine my shells when they arrived from Italy, and expressed my great desire to obtain his co-operation in my work; in which, as will appear in the sequel, I was fortunate enough to succeed.

The preparation of my first volume had now been suspended for nine months, and was not resumed till my return to London, in the beginning of March, 1829. During the spring of that year, I printed, jointly with Mr. Murchison, three memoirs, containing observations made by us in 1828, in Auvergne, Cantal, and the country of

Aix in Provence. * In consequence of this and other delays, my first volume was not completed when another summer arrived, and I again took the field to examine "the Crag," on the coasts of Essex, Norfolk, and Suffolk. The volume at length appeared in January, 1830, after which I applied myself to the revision of what I had written on "the changes in the organic world;" a subject which merely occupied four or five chapters in my original sketch, but which was soon expanded into a small treatise. While thus occupied, another summer overtook me, and I set out on a geological expedition to the south of France, the Pyrenees, and Catalonia.

On my return to Paris, in September, 1830, I studied for six weeks in the museum of M. Deshayes, examining his collection of fossil and recent shells, and profiting by his instructions in conchology. As he had not yet published any of the general results deducible from his valuable collection, I requested him to furnish me with lists of those species of shells which were common

* These papers were all read before the Geological Society of London, and were as follows :— On the Excavation of Valleys, as illustrated by the Volcanic Rocks of Central France. *Edin. New Phil. Journ.*, July, 1829. — Sur les Dépôts Lacust. Tertiaires du Cantal, avec les Roches Primordiales et Volcaniques. *Ann. des Sci. Nat.*, Oct. 1829. — On the Tertiary Freshwater Formations of Aix in Provence. *Edin. New Phil. Journ.*, Oct. 1829.

to two or more tertiary periods, as also the names of those known to occur both in some tertiary strata and in a living state. This he engaged to do, and we agreed that the information should be communicated in a tabular form. After several modifications of the plan first proposed for the Tables, we finally agreed upon the manner in which they should be constructed, and the execution was left entirely in the hands of M. Deshayes, in whose name they were to appear in my second volume.

The tables were sent to me in the course of the following spring (1831), and additions and corrections several months later. They contained not only the information which I had expected, but much more, for the names of several hundred species were added, as being common to two or more *formations* of the same *period*; whereas it was originally proposed to insert those only which were known to be common to two or more *distinct periods*.

The names thus added greatly increased the value of the tables themselves, but caused them rather to exceed the limits which could reasonably be allotted to fossil conchology in a geological work. In such works we can only hope to illustrate the more important theoretical points by catalogues of shells which characterize par-

ticular periods, as being exclusively confined to them, or which show the connection of two periods, by being common to each. The tables, although printed in the spring of 1831, were not published till two years afterwards; for, in the summer of 1831, I made a geological excursion to the volcanic district of the Eifel, and on my return determined to extend my work to three volumes, the second of which appeared without the Tables, in January, 1832. This volume I dedicated to my friend Mr. Broderip, then Vice-President of the Geological Society, in acknowledgment of the valuable assistance which he had afforded me in several departments of natural history.

During the early part of the year 1832, I printed the first half of the third volume; but, in the spring, a second edition of the first and second volumes being called for, some time was occupied in their correction. Finding that I should be unable to finish the last volume before the summer, I communicated to the public my views respecting the tertiary formations in a course of lectures delivered in May and June, at King's College, London. I then made a tour on the continent up the valley of the Rhine to Switzerland, and on my way home visited the Valorsine, where I had an opportunity of verifying the ob-

servations of M. Necker on the granite veins and altered stratified rocks of that district.

The third volume was at length published in May, 1833, having been carefully revised by my friend Mr. Lonsdale of the Geological Society, who had suggested many improvements. It was dedicated to Mr. Murchison, as containing, among other matters, the results of some of our joint labours in the field, in Auvergne, Velay, and Piedmont.

After a tour, in the summer of the same year, through part of France, Belgium, Wurtemberg, and Bavaria, I found, on my return to England in the autumn, that the second edition of the first volume was nearly out of print. I then applied myself diligently to the revision of the whole work, having resigned the Professorship which I had held for two years at King's College, in order that nothing might thenceforth interrupt my labours in the closet or the field. More than six years had elapsed since the first chapters of the "Principles" were written; and when I considered the quantity of new facts brought to light in the interval, the new memoirs and treatises published in England, Germany, and France, and the old opinions which required modification or rejection, I was often reminded of Waller's lamentation, that the poems of Chaucer had so

soon become antiquated, and his anticipations that his own and those of his contemporaries would soon share the same fate : —

“ We write in sand, our language grows,
And, like the tide, our work o’erflows.”

It would be impossible for me to enumerate all the minor corrections which I have now made, but it may be useful to those who have already studied my work, to refer at once to the places where new matter has been introduced, or where opinions formerly expressed have been modified or renounced. Of these I subjoin the following list : —

*List of the principal Additions, Alterations, and Omissions in the Third Edition.**

3d Ed.				1st Ed.		2d Ed.	
VOL.	P.			VOL.	P.	VOL.	P.
I.	4.	Geology compared to History	-	I.	2.	I.	3.
	23.	Doctrine of the Gerbanites (note)			17.		20.
	29.	Works of Avicenna	-		21.		24.
	31.	Allegorical passage from the Arabian Kazwini	-		23.		26.
	27.	Steno’s theory	-		39.		32.
	45.	Theory of Leibnitz	-		40.		45.
	70.	Gesner’s Treatise on Fossils	-		49.		56.
	75.	Fuchsel’s writings	-		47.		59.
	98.	De Luc’s theory	-		69.		79.
	102.	Remarks on the modern progress of geology	-		71.		82.

* This Edition is called the Third to prevent confusion, two out of three volumes having previously passed through two editions.

PREFACE

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3d Ed.	<i>List of Additions, &c.</i>	1st Ed.	2d Ed.
VOL. P.		VOL. P.	VOL. P.
I. 108.	Chap. v. book i. On the assumed discordance of ancient and modern causes (recast) - -	I. 75.	I. 85.
148.	Speculations on plants of tropical forms living in arctic regions -	100.	116.
160.	Maximum density of salt-water -	108.	125.
163.	Difference of climates of northern and southern hemispheres -	109.	127.
179.	Changes in physical geography as connected with climate, with a new map, showing the position of land and sea which might produce the extremes of heat and cold -	121.	139.
203.	Theory of central heat - -	141.	162.
206.	Sir John Herschel on the astronomical causes of change of climate	143.	165.
219.	Fossil plants, and theory of progressive development - -	146.	169.
229.	Recent origin of man (remainder of chap. ix. recast) - -	154.	178.
255.	Removing power of ice -	175.	202.
282.	Theory of springs, and observations on Artesian wells (added) -	198.	227.
329.	Level of the Baltic, and supposed elevation of land in Scandinavia -	227.	263.
361.	On the quantity of sediment in the waters of the Ganges - -	246.	283.
378.	Causes of currents - -	257.	295.
401.	Lowestoff Ness - -	271.	311.
407.	Reculver and Isle of Thanet -	276.	315.
II. 16.	Precipitation of salt in the Mediterranean - - -	296.	338.
80.	Doggerbank - -	307.	350.
41.	Volcanos of the Andes -	314.	361.
46.	Earthquakes in Canada -	317.	364.
53.	Samothracian deluge - -	320.	364.
82.	Phenomena of fluid lava -	342.	393.

3d Ed.	<i>List of Additions, &c.</i>	1st Ed.	2d Ed.
VOL. P.		VOL. P.	VOL. P.
II. 144.	Submarine volcanos and Graham Island, with new cuts -	I. 385.	I. 446.
150.	Theory of elevation craters (recast with additions) - -	385.	442.
178.	Chilian earthquake - -	401.	462.
184.	Cutch earthquake (with a new map)	405.	466.
194.	Quebec earthquakes - -	410.	473.
202.	Dolomieu on effects of Calabrian earthquake - - -	414.	479.
231.	Reflections on the amount of human suffering caused by earthquakes -	430.	495.
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242.	Retreat of the sea during earth- quakes - - -	471.	506.
268.	When the Temple of Serapis sank and rose - - - -	456.	527.
273.	On the causes of volcanic heat (this chapter almost entirely new)	461.	531.
296.	On the causes of earthquakes (a great part of this chapter also new)	ib.	ib.
323.	Introductory observations -	II. 1.	II. 1.
439.	Migrations of the Lemings -	94.	98.
III. 22.	Diffusion of birds by man -	121.	126.
96.	On the supposed numbers of species of animals and plants - -	181.	187.
102.	Introductory observations -	185.	191.
113.	(Controversial matter omitted here)	194.	201.
120.	Change of climate by clearing of wood - - -	202.	209.
139.	Fossils, &c. in blown sand (ar- rangement of this part altered) -	234.	240.
146.	Alluvium - - -	228.	234.
150.	Preservation of organic remains in caves and fissures—origin of caves — new discoveries in the Morea -	219.	225.
201.	Submarine forest - -	268.	274.
250.	Concluding remarks - -	- III. 7.	

3d Ed.	<i>List of Additions, &c.</i>	1st Ed.
VOL. P.		VOL. P.
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316.	A new map of part of Sicily - -	62.
369.	Proofs of modern changes in the earth's crust at great depths in Sicily - -	105.
398.	Parallel beaches, &c. - -	132.
403.	Recent limestone, &c. of Timor and Australia - - - -	136.
423.	Erratic blocks - - - -	148.
408.	Loess of the Valley of the Rhine (recast, and several opinions modified or rejected) -	151.
IV. 11.	Capt. Bayfield on new deposits in Canada	163.
20.	Modern delta of the Kander in Switzerland	170.
54.	Lake craters of the Eifel, and age of Rhine volcanos (concluding part of this chapter recast, with additions and corrections) -	198.
79.	Tertiary strata of Mayence - -	215.
80.	Tertiary strata of Osnabruch - -	ib.
100.	Indusial limestone (new illustrations) -	232.
155.	Vicentine formations - -	277.
181.	Proofs that the elevation of the Weald was gradual - - - -	297.
197.	Valleys of elevation, how caused -	309.
198.	The concluding part of this chapter recast and newly illustrated - - -	310.
211.	Sketch of the principal secondary formations (this chapter greatly enlarged) - -	324.
246.	This chapter on the elevation of mountain-chains in part re-written and condensed -	337.
281.	Alterations by dikes an imperfect analogy, &c.	367.
284.	Faraday on carbonic acid becoming gaseous	370.

I must also mention the important omission from the Appendix of M. Deshayes's Tables of

Shells, and some lists of tertiary fossils formerly given, which together would have occupied eighty pages had they been reprinted, augmenting considerably the size and cost of the work. I have by no means altered my opinion in regard to the scientific value of the tables; but they have already circulated extensively among geologists; 2500 copies of the third volume having been printed, and some few of these being still unsold and to be had separately by such as desire to possess the Appendix in full.

I have now only to express my acknowledgments to Dr. Fitton, for the many valuable hints which he has afforded me in revising many parts of the third edition. At his suggestion, and that of Mr. Lonsdale, I have prefixed to the table of contents a brief summary of the whole work, in order to show the connexion of its several parts. If any of my readers should be lost in the details, especially those relating to natural history in the third book, and should be unable to see the direct bearing of these on the more strictly geological parts of the work, they are invited to refer from time to time to the summary, and to consult at the same time the abridged table of contents which follows it.

The glossary at the end of the fourth volume will assist those beginners who are unacquainted

with the elements of geology, especially in reading a part of the first book, where, as I have stated (Vol. I. p. 126.), the novice is carried beyond his depth by the discussion of certain controverted theories, which were thought well calculated to stimulate curiosity, and to lead to the more diligent study of the facts afterwards described.*

* The explanation of the Plates will be found in the pages where the Binder is directed to insert them. In the smaller Map, Plate V., the dotted line *a a* expresses the occasional channels through which the waters of the Indus flow during inundations.

London, May 20. 1834.

SUMMARY
OF THE
PRINCIPLES OF GEOLOGY.

(See Preface, p. xxiv.)

AFTER some observations on the nature and objects of geology (Chap. I.), a sketch is given of the progress of opinion in this science, from the times of the earliest known writers to our own days (Chaps. II. III. IV.). From this historical sketch it appears that the first cultivators of geology indulged in a succession of visionary and fantastical theories, the errors of which the author refers for the most part to one common source,—a prevailing persuasion, that the ancient and existing causes of change were different, both as regards their nature and energy; in other words, they supposed that the causes by which the crust of the earth, and its habitable surface, have been modified at remote periods, were quite distinct from the operations by which the surface and crust of the planet are now undergoing a gradual change. The prejudices which have led to this assumed discordance of ancient and modern causes are then considered (Chap. V. to p. 121. Vol. I.), and the author contends, that neither the imagined universality of certain sedimentary formations (Chap. V.), nor the different climates which

formerly pervaded the northern hemisphere (Chaps. VI. VII. VIII.), nor the alleged progressive development of organic life (Chap. IX.), lend any solid support to the assumption.

The numerous topics of general interest brought under review in discussing this fundamental question are freely enlarged upon, in the hope of stimulating the curiosity of the reader. It is presumed that when he has convinced himself, that the forces formerly employed to remodel the crust of the earth were the same in kind and energy as those now acting, or even if he perceives that the opposite hypothesis is, at least, questionable, he will enter upon the study of the two treatises which follow (on the changes now in progress in the organic and inorganic world, Books II. and III.) with a just sense of the importance of their subject-matter.

The first of these treatises which relates to the changes of the inorganic creation, such as are known to have taken place within the historical era, is divided into two parts. In the first an account is given of the observed effects of aqueous causes, such as rivers, springs, tides, and currents (Book II. Part I.), while in the second the effects and probable causes of the volcano and earthquake are considered (Book II. Part II.).

The treatise on the changes of the organic world is also divisible into two parts, the first of which comprehends all questions relating to the variability of species, and the limits assigned to their duration (Chaps. I. to XI.). The second explains the processes by which the remains of animals and plants existing at any particular period may be preserved (Chaps. XII. to XVII.).

Under the first of these divisions, the author defines the term *species*, and combats the notion that one species may be gradually converted into another, by insensible modifications in the course of ages (Chaps. I. II. III. and IV.). He also enters into a full examination of the evidence regarded by him as conclusive in favour of the limited durability of species. In proof of this, he argues that the geographical distribution of species being partial, the changes constantly going on in the animate and inanimate world must constantly tend to their extinction (Chaps. V. to X.). Whether new species are substituted for those which die out, is a topic on which no speculations are offered; but it is contended that if new species had been introduced from time to time as often as others have been lost, we should have no reason to expect to be able to establish the fact during the limited period of our observation (Chap. XI.).

In the second branch of this treatise, the various circumstances under which aquatic and terrestrial plants and animals, as also man and the works of his hands, become fossil, are examined (Chaps. XIII. to XVII.).

The fourth book is occupied with the description of geological monuments strictly so called, the formations termed tertiary being first more fully examined and classified, the secondary and primary rocks being afterwards more briefly alluded to. In the course of this description, it appears that the rocks which compose the crust of the earth have resulted in part from igneous and partly from aqueous causes, and others from the combined influence of these agents, the igneous having operated both upon and far beneath the surface. The bearing of the various phenomena

considered in the second book on the interpretation of such monuments cannot fail to be seen.

It is, moreover, shown, that the fossil remains of distinct plants and animals are plentifully included in aqueous rocks of distinct ages, and, consequently, that the same species have not always flourished on the earth. It is principally by the aid of such fossils, that the chronological arrangement of rocks is determined; and a careful comparison of the numerous organic remains of the tertiary formations affords some indication of a gradual introduction of the species now living, and a successive extinction of species which previously existed. It is at least clear that during the tertiary epoch entire assemblages of species were not simultaneously swept away from large regions, and others perfectly distinct created in their place. The intimate connection of such conclusions, with the subjects investigated in the third book, is sufficiently obvious.

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ERRATA ET ADDENDA.

Vol. I.

- Page 25. note, for "Strabo, lib. ii." read "Strabo, Geog. lib. i. Edit. Almelov. Amst. 1707."
 202. Count Sternberg. I have since learnt that I was misinformed, and that this criticism was not by Count Sternberg.
 209. line 5. for "M. Amie Boué" read "M. Ami Boué."

Vol. II.

- Page 51. line 10. from bottom, for "300 feet" read "350 feet."
 89. line 13. for "Erhebung" read "Erhebungs."
 237. note, for "Raffles's Hist. of Java" read "Von Hoff, vol. ii. p. 444."
 258. line 5. from bottom, for "fifth" read "sixth."
 — last line, for "frustra" read "flustra."
 305. first line, for "thickness" read "length."

DIRECTIONS TO THE BINDER.

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PRINCIPLES OF GEOLOGY.

BOOK I.

CHAPTER I.

Geology defined — Compared to History — Its relation to other Physical Sciences — Not to be confounded with Cosmogony.

GEOLOGY is the science which investigates the successive changes that have taken place in the organic and inorganic kingdoms of nature: it inquires into the causes of these changes, and the influence which they have exerted in modifying the surface and external structure of our planet.

By these researches into the state of the earth and its inhabitants at former periods, we acquire a more perfect knowledge of its *present* condition, and more comprehensive views concerning the laws *now* governing its animate and inanimate productions. When we study history, we obtain a more profound insight into human nature, by instituting a comparison between the present and former states of society. We trace the long series of events which have gradually led to the actual posture of affairs; and by connecting effects with their causes, we are enabled to classify and retain in the memory a multitude of complicated relations — the various peculiarities of national character — the dif-

ferent degrees of moral and intellectual refinement, and numerous other circumstances, which, without historical associations, would be uninteresting or imperfectly understood. As the present condition of nations is the result of many antecedent changes, some extremely remote and others recent, some gradual, others sudden and violent, so the state of the natural world is the result of a long succession of events; and if we would enlarge our experience of the present economy of nature, we must investigate the effects of her operations in former epochs.

We often discover with surprise, on looking back into the chronicles of nations, how the fortune of some battle has influenced the fate of millions of our contemporaries, when it has long been forgotten by the mass of the population. With this remote event we may find inseparably connected the geographical boundaries of a great state, the language now spoken by the inhabitants, their peculiar manners, laws, and religious opinions. But far more astonishing and unexpected are the connections brought to light, when we carry back our researches into the history of nature. The form of a coast, the configuration of the interior of a country, the existence and extent of lakes, valleys, and mountains, can often be traced to the former prevalence of earthquakes and volcanos in regions which have long been undisturbed. To these remote convulsions the present fertility of some districts, the sterile character of others, the elevation of land above the sea, the climate, and various peculiarities, may be distinctly referred. On the other hand, many distinguishing features of the surface may often be ascribed to the operation at a remote era of slow and tranquil causes—to the gradual deposition of sediment in a

lake or in the ocean, or to the prolific increase of testacea and corals.

To select another example, we find in certain localities subterranean deposits of coal, consisting of vegetable matter, formerly drifted into seas and lakes. These seas and lakes have since been filled up, the lands whereon the forests grew have disappeared or changed their form, the rivers and currents which floated the vegetable masses can no longer be traced, and the plants belonged to species which for ages have passed away from the surface of our planet. Yet the commercial prosperity, and numerical strength of a nation, may now be mainly dependent on the local distribution of fuel determined by that ancient state of things.

Geology is as intimately related to almost all the physical sciences, as is history to the moral. An historian should, if possible, be at once profoundly acquainted with ethics, politics, jurisprudence, the military art, theology; in a word, with all branches of knowledge, whereby any insight into human affairs, or into the moral and intellectual nature of man, can be obtained. It would be no less desirable that a geologist should be well versed in chemistry, natural philosophy, mineralogy, zoology, comparative anatomy, botany; in short, in every science relating to organic and inorganic nature. With these accomplishments, the historian and geologist would rarely fail to draw correct and philosophical conclusions from the various monuments transmitted to them of former occurrences. They would know to what combination of causes analogous effects were referrible, and they would often be enabled to supply, by inference, information concerning many events unrecorded in the defective

archives of former ages. But as such extensive acquisitions are scarcely within the reach of any individual, it is necessary that they who have devoted their lives to different departments should unite their efforts; and as the historian receives assistance from the antiquary, and from those who have cultivated different branches of moral and political science, so the geologist should avail himself of the aid of many naturalists, and particularly of those who have studied the fossil remains of lost species of animals and plants.

The analogy, however, of the monuments consulted in geology, and those available in history, extends no farther than as regards one class of historical monuments,—those which may be said to be *undesignedly* commemorative of former events. The canoes, for example, and stone hatchets found in our peat bogs afford an insight into the rude arts and manners of the earliest inhabitants of our island; the buried coin fixes the date of the reign of some Roman emperor; the ancient encampment indicates the districts once occupied by invading armies, and the former method of constructing military defences; the Egyptian mummies throw light on the art of embalming, the rites of sepulture, or the average stature of the human race in ancient Egypt. This class of memorials yields to no other in authenticity, but it constitutes a small part only of the resources on which the historian relies, whereas in geology it forms the only kind of evidence which is at our command. For this reason we must not expect to obtain a full and connected account of any series of events beyond the reach of history. But the testimony of geological monuments, if frequently imperfect, possesses at least the advantage of being free from all suspicion of misrepresentation. We may

be deceived in the inferences which we draw, in the same manner as we often mistake the nature and import of phenomena observed in the daily course of nature, but our liability to err is confined to the interpretation, and, if this be correct, our information is certain.

It was long ere the distinct nature and legitimate objects of geology were fully recognized, and it was at first confounded with many other branches of inquiry, just as the limits of history, poetry, and mythology were ill-defined in the infancy of civilization. Werner appears to have regarded geology as little other than a subordinate department of mineralogy; and Desmarest included it under the head of Physical Geography. But the most common and serious source of confusion arose from the notion that it was the business of geology to discover the mode in which the present system of things originated, or, as some imagined, to study the effects of those cosmological causes which were employed by the Author of Nature to bring the planet out of a nascent and chaotic state into a more perfect and habitable condition. Hutton was the first who endeavoured to draw a strong line of demarcation between his favourite science and cosmogony, for he declared that geology was in no ways concerned "with questions as to the origin of things."

An attempt will be made in the sequel of this work to demonstrate that geology differs as widely from cosmogony, as speculations concerning the mode of the first creation of man differ from history. But, before entering more at large on this controverted question, I shall endeavour to trace the progress of opinion on this topic, from the earliest ages, to the commencement of the present century.

CHAPTER II.

HISTORICAL SKETCH OF THE PROGRESS OF GEOLOGY.

Oriental Cosmogony— Doctrine of the successive destruction and renovation of the world— Origin of this doctrine— Common to the Egyptians— Adopted by the Greeks— System of Pythagoras— Of Aristotle— Dogmas concerning the extinction and reproduction of genera and species— Strabo's theory of elevation by earthquakes— Pliny— Concluding Remarks on the knowledge of the Ancients.

Oriental Cosmogony.— THE earliest doctrines of the Indian and Egyptian schools of philosophy agreed in ascribing the first creation of the world to an omnipotent and infinite Being. They concurred also in representing this Being, who had existed from all eternity, as having repeatedly destroyed and reproduced the world and all its inhabitants. In the "Institutes of Menù," the sacred volume of the Hindoos, to which, in its present form, Sir William Jones ascribes an antiquity of at least eight hundred and eighty years before Christ, we find this system of the alternate destruction and renovation of the world, proposed in the following remarkable verses:—

"The Being, whose powers are incomprehensible, having created me (Menù) and this universe, again became absorbed in the supreme spirit, changing the time of energy for the hour of repose."

"When that power awakes, then has this world its full expansion; but when he slumbers with a tranquil spirit, then the whole system fades away. . . . For

while he reposes as it were, embodied spirits endowed with principles of action depart from their several acts, and the mind itself becomes inert."

Menù then describes the absorption of all beings into the Supreme essence, and the Divine soul itself is said to slumber, and to remain for a time immersed in "the first idea, or in darkness." He then proceeds (verse fifty-seven), "Thus that immutable power, by waking and reposing alternately, revivifies and destroys, in eternal succession, this whole assemblage of locomotive and immoveable creatures."

It is then declared that there has been a long succession of *manwantaras*, or periods, each of the duration of many thousand ages, and —

"There are creations also, and destructions of worlds innumerable: the Being, supremely exalted, performs all this with as much ease as if in sport, again and again, for the sake of conferring happiness."*

The compilation of the ordinances of Menù was not all the work of one author nor of one period, and to this circumstance some of the remarkable inequalities of style and matter are probably attributable. There are many passages, however, wherein the attributes and acts of the "Infinite and Incomprehensible Being" are spoken of with much grandeur of conception and sublimity of diction, as some of the passages above cited, though sufficiently mysterious, may serve to exemplify. There are at the same time such puerile conceits and monstrous absurdities in the same cosmogony, that some may impute to mere accident any slight approximation to truth, or apparent coincidence

* Institutes of Hindoo Law, or the Ordinances of Menù, from the Sanscrit, translated by Sir William Jones, 1796.

between the oriental dogmas and observed facts. This pretended revelation, however, was not purely an effort of the unassisted imagination, nor invented without regard to the opinions and observations of naturalists. There are introduced into the same chapter certain astronomical theories, evidently derived from observation and reasoning. Thus, for instance, it is declared that, at the North Pole, the year was divided into a long day and night, and that their long day was the northern, and their night the southern course of the sun; and to the inhabitants of the moon, it is said, one day is equal in length to one month of mortals.* If such statements cannot be resolved into mere conjectures, we have no right to refer to mere chance the prevailing notion, that the earth and its inhabitants had formerly undergone a succession of revolutions and catastrophes interrupted by long intervals of tranquillity.

Now there are two sources in which such a theory may have originated. The marks of former convulsions on every part of the surface of our planet are obvious and striking. The remains of marine animals imbedded in the solid strata are so abundant, that they may be expected to force themselves on the observation of every people who have made some progress in refinement; and especially where one class of men are expressly set apart from the rest for study and contemplation. If these appearances are once recognized, it seems natural that the mind should come to the conclusion, not only of mighty changes in past ages, but of alternate periods of repose and disorder; — of repose when the fossil animals lived, grew, and multiplied — of disorder, when the strata wherein they

* Menù, *Inst.* c. i. 66. and 67.

were buried became transferred from the sea to the interior of continents, and entered into high mountain chains. Those modern writers, who are disposed to disparage the former intellectual advancement and civilization of eastern nations, might concede some foundation of observed facts for the curious theories now under consideration, without indulging in exaggerated opinions of the progress of science; especially as universal catastrophes of the world, and exterminations of organic beings, in the sense in which they were understood by the Brahmin, are untenable doctrines.

We know, that the Egyptian priests were aware, not only that the soil beneath the plains of the Nile, but that also the hills bounding the great valley, contained marine shells*; and it could hardly have escaped the observation of eastern philosophers, that some soils were filled with fossil remains, since so many national works were executed on a magnificent scale by oriental monarchs in very remote eras. Great canals and tanks required extensive excavations; and we know that in more recent times (the fourteenth century of our era) the removal of soil necessary for such undertakings brought to light geological phenomena, which attracted the attention of a people less civilized than were many of the older nations of the East.†

* Herodot. Euterpe, 12.

† This circumstance is mentioned in a Persian MS. copy of the historian Ferishta, in the library of the East India Company, relating to the rise and progress of the Mahomedan empire in India, and procured from the library of Tippoo Sultan in 1799; and has been recently referred to at some length by Dr. Buckland. — (Geol. Trans. 2d Series, vol. ii. part iii. p. 389.) — It

But although the Brahmins, like the priests of Egypt, may have been acquainted with the existence of fossil remains in the strata, it is possible that the doctrine of successive destructions and renovations of the world merely received corroboration from such proofs ; and that it may have been originally handed down, like the religious dogmas of most nations, from a ruder state of society. The system may have had its source in the exaggerated traditions of those partial, but often dreadful, catastrophes, which are sometimes occasioned by particular combinations of natural causes. Floods and volcanic eruptions, the agency of water and fire, are the chief instruments of devastation on our globe ; and we shall point out in the sequel the extent of many of these calamities, recurring at distant intervals of time, in the present course of nature ; and shall only observe here, that they are so peculiarly calculated to inspire a lasting terror, and are so often fatal in their consequences to great multitudes of people, that it scarcely requires a passion for the marvellous, so characteristic of rude and half civilized nations, still less the exuberant imagination of eastern writers, to augment them into general cataclysms and conflagrations.

Humboldt relates the interesting fact, that after the annihilation of a large part of the inhabitants of Cumana, by an earthquake in 1766, a season of ex-

is stated that, in the year 762 (or 1360 of our era), the king employed fifty thousand labourers in cutting through a mound, so as to form a junction between the rivers Selima and Sutluj ; and in this mound were found the bones of elephants and men, some of them petrified, and some of them resembling bone. The gigantic dimensions attributed to the human bones show them to have belonged to some of the larger pachydermata.

traordinary fertility ensued, in consequence of the great rains which accompanied the subterranean convulsions. “The Indians,” he says, “celebrated, after the ideas of an antique superstition, by festivals and dancing, the destruction of the world and the approaching epoch of its regeneration.”*

The existence of such rites among the rude nations of South America is most important, for it shows what effects may be produced by great catastrophes of this nature, recurring at distant intervals of time, on the minds of a barbarous and uncultivated race. The superstitions of a savage tribe are transmitted through all the progressive stages of society, till they exert a powerful influence on the mind of the philosopher. He may find, in the monuments of former changes on the earth’s surface, an apparent confirmation of tenets handed down through successive generations, from the rude hunter, whose terrified imagination drew a false picture of those awful visitations of floods and earthquakes, whereby the whole earth as known to him was simultaneously devastated.

Egyptian Cosmogony.—Respecting the cosmogony of the Egyptian priests, we gather much information from writers of the Grecian sects, who borrowed almost all their tenets from Egypt, and amongst others that of the former successive destruction and renovation of the world.† We learn from Plutarch, that this was the theme of one of the hymns of Orpheus, so celebrated in the fabulous ages of Greece. It was brought by him from the banks of the Nile; and we even find in his verses, as in the Indian systems, a definite period assigned for the duration of

* Humboldt et Bonpland, Voy. Relat. Hist. vol. i. p. 30.

† Prichard’s Egypt. Mythol. p. 177.

each successive world.* The returns of great catastrophes were determined by the period of the *Annus Magnus*, or great year, — a cycle composed of the revolutions of the sun, moon, and planets, and terminating when these return together to the same sign whence they were supposed at some remote epoch to have set out. The duration of this great cycle was variously estimated. According to Orpheus, it was 120,000 years; according to others, 300,000; and by Cassander it was taken to be 360,000 years.†

We learn particularly from the *Timæus* of Plato, that the Egyptians believed the world to be subject to occasional conflagrations and deluges, whereby the gods arrested the career of human wickedness, and purified the earth from guilt. After each regeneration, mankind were in a state of virtue and happiness, from which they gradually degenerated again into vice and immorality. From this Egyptian doctrine, the poets derived the fable of the decline from the golden to the iron age. The sect of Stoics adopted most fully the system of catastrophes destined at certain intervals to destroy the world. These they taught were of two kinds;—the *Cataclysm*, or destruction by deluge, which sweeps away the whole human race, and annihilates all the animal and vegetable productions of nature; and the *Ecpyrosis*, or conflagration, which dissolves the globe itself. From the Egyptians also they derived the doctrine of the gradual debasement of man from a state of innocence. Towards the termination of each era the gods could no longer bear with the wickedness of men, and a shock of the elements or a deluge over-

* *Plut. de Defectu Oraculorum*, cap. 12. *Censorinus de Die Natali*. See also *Prichard's Egypt. Mythol.* p. 182.

† *Prichard's Egypt. Mythol.* p. 182.

whelmed them ; after which calamity, Astrea again descended on the earth, to renew the golden age.*

The connection between the doctrine of successive catastrophes and repeated deteriorations in the moral character of the human race, is more intimate and natural than might at first be imagined. For, in a rude state of society, all great calamities are regarded by the people as judgments of God on the wickedness of man. Thus, in our own time, the priests persuaded a large part of the population of Chili, and perhaps believed themselves, that the fatal earthquake of 1822 was a sign of the wrath of Heaven for the great political revolution just then consummated in South America. In like manner, in the account given to Solon by the Egyptian priests, of the submersion of the island of Atlantis under the waters of the ocean, after repeated shocks of an earthquake, we find that the event happened when Jupiter had seen the moral depravity of the inhabitants.† Now, when the notion had once gained ground, whether from causes before suggested or not, that the earth had been destroyed by several general catastrophes, it would next be inferred that the human race had been as often destroyed and renovated. And, since every extermination was assumed to be *penal*, it could only be reconciled with divine justice, by the supposition that man, at each successive creation, was regenerated in a state of purity and innocence.

A very large portion of Asia, inhabited by the earliest nations whose traditions have come down to us, has been always subject to tremendous earthquakes. Of the geographical boundaries of these, and their effects, I shall speak in the proper place. Egypt

* Prichard's Egypt. Mythol. p. 193.

† Plato's *Timæus*.

has, for the most part, been exempt from this scourge, and the tradition of catastrophes in that country was perhaps derived from the East.

One extraordinary fiction of the Egyptian mythology was the supposed intervention of a masculo-feminine principle, to which was assigned the development of the embryo world, somewhat in the way of incubation. For the doctrine was, that when the first chaotic mass had been produced, in the form of an egg, by a self-dependent and eternal Being, it required the mysterious functions of this masculo-feminine demi-urgus to reduce the component elements into organized forms.

Although it is scarcely possible to recall to mind this conceit without smiling, it does not seem to differ essentially in principle from some cosmological notions of men of great genius and science in modern Europe. The Egyptian philosophers ventured on the perilous task of seeking from among the processes now going on something analogous to the mode of operation employed by the Author of Nature in the first creation of organized beings, and they compared it to that which governs the birth of new individuals by generation. To suppose that some general rules might be observed in the first origin of created beings, or the first introduction of new species into our system, was not absurd, nor inconsistent with any thing known to us in the economy of the universe. But the hypothesis, that there was any analogy between such laws, and those employed in the continual reproduction of species once created, was purely gratuitous. In like manner, it is not unreasonable, nor derogatory to the attributes of Omnipotence, to imagine that some general laws may be observed in the creation of new worlds ; and if man could witness the birth of such worlds, he might reason

by induction upon the origin of his own. But in the absence of such data, an attempt has been made to fancy some analogy between the agents now employed to destroy, renovate, and perpetually vary the earth's surface, and those whereby the first chaotic mass was formed, and brought by supposed nascent energy from the embryo to the habitable state.

By how many shades the elaborate systems, constructed on these principles, may differ from the mysteries of the "Mundane Egg" of Egyptian fable, I shall not inquire. It would, perhaps, be dangerous ground, and some of our contemporaries might not sit as patiently as the Athenian audience, when the fiction of the chaotic egg, engrafted by Orpheus upon their own mythology, was turned into ridicule by Aristophanes. That comedian introduced his birds singing, in a solemn hymn, "How sable-plumaged Night conceived in the boundless bosom of Erebus, and laid an egg, from which, in the revolution of ages, sprung Love, resplendent with golden pinions. Love fecundated the dark-winged chaos, and gave origin to the race of birds."*

Pythagorean Doctrines.—Pythagoras, who resided for more than twenty years in Egypt, and, according to Cicero, had visited the East, and conversed with the Persian philosophers, introduced into his own country, on his return, the doctrine of the gradual deterioration of the human race from an original state of virtue and happiness: but if we are to judge of his theory concerning the destruction and renovation of the earth from the sketch given by Ovid, we must concede it to have been far more philosophical than

* Aristophanes, *Birds*, 694.

any known version of the cosmologies of oriental or Egyptian sects.

Although Pythagoras is introduced by the poet as delivering his doctrine in person, some of the illustrations are derived from natural events which happened after the death of the philosopher. But notwithstanding these anachronisms, we may regard the account as a true picture of the tenets of the Pythagorean school in the Augustan age; and although perhaps partially modified, it must have contained the substance of the original scheme. Thus considered, it is extremely curious and instructive; for we here find a comprehensive and masterly summary of almost all the great causes of change now in activity on the globe, and these adduced in confirmation of a principle of perpetual and gradual revolution inherent in the nature of our terrestrial system. These doctrines, it is true, are not directly applied to the explanation of *geological* phenomena; or, in other words, no attempt is made to estimate what may have been in past ages, or what may hereafter be, the aggregate amount of change brought about by such never-ending fluctuations. Had this been the case, we might have been called upon to admire so extraordinary an anticipation with no less interest than astronomers, when they endeavour to divine by what means the Samian philosopher came to the knowledge of the Copernican theory.

Let us now examine the celebrated passages to which we have been adverting*:—

“ Nothing perishes in this world; but things merely vary and change their form. To be born, means simply that a thing begins to be something different from what

* Ovid's *Metamor.* lib. 15.

it was before ; and dying, is ceasing to be the same thing. Yet, although nothing retains long the same image, the sum of the whole remains constant." These general propositions are then confirmed by a series of examples, all derived from natural appearances, except the first, which refers to the golden age giving place to the age of iron. The illustrations are thus consecutively adduced.

1. Solid land has been converted into sea.

2. Sea has been changed into land. Marine shells lie far distant from the deep, and the anchor has been found on the summit of hills.

3. Valleys have been excavated by running water, and floods have washed down hills into the sea.*

4. Marshes have become dry ground.

5. Dry lands have been changed into stagnant pools.

6. During earthquakes some springs have been closed up, and new ones have broken out. Rivers have deserted their channels, and have been re-born elsewhere ; as the Erasinus in Greece, and Mysus in Asia.

7. The waters of some rivers, formerly sweet, have become bitter, as those of the Anigris in Greece, &c.†

8. Islands have become connected with the main land, by the growth of deltas and new deposits, as in the case of Antissa joined to Lesbos, Pharos to Egypt, &c.

9. Peninsulas have been divided from the main land, and have become islands, as Leucadia ; and according

* *Eluvie mons est deductus in æquor*, v. 267. The meaning of this last verse is somewhat obscure, but, taken with the context, may be supposed to allude to the abrading power of floods, torrents, and rivers.

† The impregnation from new mineral springs, caused by earthquakes in volcanic countries, is, perhaps, here alluded to.

to tradition Sicily, the sea having carried away the isthmus.

10. Land has been submerged by earthquakes: the Grecian cities of Helice and Buris, for example, are to be seen under the sea, with their walls inclined.

11. Plains have been upheaved into hills by the confined air seeking vent, as at Trœzen in the Peloponnesus.

12. The temperature of some springs varies at different periods. The waters of others are inflammable.*

13. There are streams which have a petrifying power, and convert the substances which they touch into marble.

14. Extraordinary medicinal and deleterious effects are produced by the water of different lakes and springs.†

15. Some rocks and islands, after floating, and having been subject to violent movements, have at length become stationary and immoveable, as Delos, and the Cyanean Isles.‡

* This is probably an allusion to the escape of inflammable gas, like that in the district of Baku, west of the Caspian; at Pietramala, in the Tuscan Apennines; and several other places.

† Many of those described seem fanciful fictions, like the virtues still so commonly attributed to mineral waters.

‡ Raspe, in a learned and judicious essay (*De Novis Insulis*, cap. 19.), has made it appear extremely probable that all the traditions of certain islands in the Mediterranean having at some former time frequently shifted their positions, and at length become stationary, originated in the great change produced in their form by earthquakes and submarine eruptions, of which there have been modern examples in the new islands raised in the time of history. When the series of convulsions ended, the island was said to become fixed.

16. Volcanic vents shift their position ; there was a time when Etna was not a burning mountain, and the time will come when it will cease to burn. Whether it be that some caverns become closed up by the movements of the earth, and others opened, or whether the fuel is finally exhausted, &c. &c.

The various causes of change in the inanimate world having been thus enumerated, the doctrine of equivocal generation is next propounded, as illustrating a corresponding perpetual flux in the animate creation.*

In the Egyptian and Eastern cosmogonies, and in the Greek version of them, no very definite meaning can, in general, be attached to the term "destruction of the world;" for sometimes it would seem almost to imply the annihilation of our planetary system, and at others a mere revolution of the surface of the earth.

Opinions of Aristotle. — From the works now extant of Aristotle, and from the system of Pythagoras, as above exposed, we might certainly infer that these

* It is not inconsistent with the Hindoo mythology to suppose that Pythagoras might have found in the East not only the system of universal and violent catastrophes and periods of repose in endless succession, but also that of periodical revolutions, effected by the continued agency of ordinary causes. For Brahma, Vishnu, and Siva, the first, second, and third persons of the Hindoo triad, severally represented the Creative, the Preserving, and the Destroying powers of the Deity. The co-existence of these three attributes, all in simultaneous operation, might well accord with the notion of perpetual but partial alterations finally bringing about a complete change. But the fiction expressed in the verses before quoted from Menù, of eternal vicissitudes in the vigils and slumbers of the Infinite Being, seems accommodated to the system of great general catastrophes followed by new creations and periods of repose.

philosophers considered the agents of change now operating in nature, as capable of bringing about in the lapse of ages a complete revolution; and the Stagyrte even considers occasional catastrophes, happening at distant intervals of time, as part of the regular and ordinary course of nature. The deluge of Deucalion, he says, affected Greece only, and principally the part called Hellas, and it arose from great inundations of rivers during a rainy winter. But such extraordinary winters, he says, though after a certain period they return, do not always revisit the same places.*

Censorinus quotes it as Aristotle's opinion, that there were general inundations of the globe, and that they alternated with conflagrations, and that the flood constituted the winter of the great year, or astronomical cycle, while the conflagration, or destruction by fire, is the summer or period of greatest heat.† If this passage, as Lipsius supposes, be an amplification, by Censorinus, of what is written in "the Meteorics," it is a gross misrepresentation of the doctrine of the Stagyrte, for the general bearing of his reasoning in that treatise tends clearly in an opposite direction. He refers to many examples of changes now constantly going on, and insists emphatically on the great results which they must produce in the lapse of ages. He instances particular cases of lakes that had dried up, and deserts that had at length become watered by rivers and fertilized. He points to the growth of the Nilotic delta since the time of Homer, to the shallowing of the Palus Mæotis within sixty years from his own time; and although, in the same chapter, he says nothing of earthquakes, yet in

* Meteor. lib. i. cap. xii.

† De Die Nat.

others of the same treatise*, he shows himself not unacquainted with their effects. He alludes, for example, to the upheaving of one of the Eolian islands previous to a volcanic eruption. "The changes of the earth," he says, "are so slow in comparison to the duration of our lives, that they are overlooked (*λανθανει*); and the migrations of people after great catastrophes, and their removal to other regions, cause the event to be forgotten."†

When we consider the acquaintance displayed by Aristotle with the destroying and renovating powers of Nature in his various works, the introductory and concluding passages of the twelfth chapter of his "Meteorics" are certainly very remarkable. In the first sentence he says, "The distribution of land and sea in particular regions does not endure throughout all time, but it becomes sea in those parts where it was land, and again it becomes land where it was sea; and there is reason for thinking that these changes take place according to a certain system, and within a certain period." The concluding observation is as follows: — "As time never fails, and the universe is eternal, neither the Tanais, nor the Nile, can have flowed for ever. The places where they rise were once dry, and there is a limit to their operations, but there is none to time. So also of all other rivers; they spring up, and they perish; and the sea also continually deserts some lands and invades others. The same tracts, therefore, of the earth are not, some always sea, and others always continents, but every thing changes in the course of time."

It seems, then, that the Greeks had not only derived

* Lib. ii. cap. 14, 15, and 16.

† Ibid.

from preceding nations, but had also, in some slight degree, deduced from their own observations, the theory of periodical revolutions in the inorganic world : there is, however, no ground for imagining that they contemplated former changes in the races of animals and plants. Even the fact, that marine remains were inclosed in solid rocks, although observed by many, and even made the groundwork of geological speculation, never stimulated the industry or guided the inquiries of naturalists. It is not impossible that the theory of equivocal generation might have engendered some indifference on this subject, and that a belief in the spontaneous production of living beings from the earth, or corrupt matter, might have caused the organic world to appear so unstable and fluctuating, that phenomena indicative of former changes would not awaken intense curiosity. The Egyptians, it is true, had taught, and the Stoics had repeated, that the earth had once given birth to some monstrous animals, which existed no longer ; but the prevailing opinion seems to have been, that after each great catastrophe the same species of animals were created over again. This tenet is implied in a passage of Seneca, where, speaking of a future deluge, he says, “ Every animal shall be generated anew, and men free from guilt shall be given to the earth.” *

An old Arabian version of the doctrine of the successive revolutions of the globe, translated by Abraham Ecchellensis†, seems to form a singular exception to the general rule, for here we find the idea of different

* *Omne ex integro animal generabitur, dabiturque terris homo inscius scelerum.* — *Quæst. Nat. iii. c. 29.*

† This author was Regius Professor of Syriac and Arabic at Paris, where, in 1685, he published a Latin translation of many

genera and species having been created. The Gerbanites, a sect of astronomers who flourished some centuries before the Christian era, taught as follows: —“ That after every period of thirty-six thousand four hundred and twenty-five years, there were produced a pair of *every* species of animal, both male and female, from whom animals might be propagated and inhabit this lower world. But when a circulation of the heavenly orbs was completed, which is finished in that space of years, *other genera and species* of animals are propagated, as also of plants and other things, and the first order is destroyed, and so it goes on for ever and ever.” *

Theory of Strabo.—As we learn much of the tenets of the Egyptian and oriental schools in the writings of

Arabian MSS. on different departments of philosophy. This work has always been considered of high authority.

* Gerbanitæ docebant singulos triginta sex mille annos quadringentos, viginti quinque bina ex singulis animalium speciebus produci, marem scilicet ac feminam, ex quibus animalia propagantur, huncque inferiorem incolunt orbem. Absolutâ autem cœlestium orbium circulatione, quæ illo annorum conficitur spatio, iterum alia producuntur animalium genera et species, quemadmodum et plantarum aliarumque rerum, et primus destruitur ordo, sicque in infinitum producitur. — Histor. Orient. Suppl. per Abrahamum Ecchellensum, Syrum Maronitam, cap. 7, et 8. ad calcem Chronici Oriental. Parisiis, e Typ. regia, 1685. fol.

I have given the punctuation as in the Paris edition, there being no comma after quinque, but, at the suggestion of M. de Schlegel, I have referred the number twenty-five to the period of years, and not to the number of pairs of each species created at one time, as I had done in former editions. Fortis inferred that twenty-five new *species* only were created at a time; a construction which the passage will not admit. Mém. sur l'Hist. Nat. de l'Italie, vol. i. p. 202.

the Greeks, so many speculations of the early Greek authors are made known to us in the works of the Augustan and later ages. Strabo, in particular, enters largely, in the second book of his Geography, into the opinions of Eratosthenes and other Greeks on one of the most difficult problems in geology, viz. by what causes marine shells came to be plentifully buried in the earth at such great elevations and distances from the sea.

He notices, amongst others, the explanation of Xanthus the Lydian, who said that the seas had once been more extensive, and that they had afterwards been partially dried up, as in his own time many lakes, rivers, and wells in Asia had failed during a season of drought. Treating this conjecture with merited disregard, Strabo passes on to the hypothesis of Strato, the natural philosopher, who had observed that the quantity of mud brought down by rivers into the Euxine was so great, that its bed must be gradually raised, while the rivers still continue to pour in an undiminished quantity of water. He therefore conceived that, originally, when the Euxine was an inland sea, its level had by this means become so much elevated that it burst its barrier near Byzantium, and formed a communication with the Propontis; and this partial drainage, he supposed, had already converted the left side into marshy ground, and thus, at last, the whole would be choked up with soil. So, it was argued, the Mediterranean had once opened a passage for itself by the Columns of Hercules into the Atlantic; and perhaps the abundance of sea-shells in Africa, near the Temple of Jupiter Ammon, might also be the deposit of some former inland sea, which had at length forced a passage and escaped.

But Strabo rejects this theory as insufficient to ac-

count for all the phenomena, and he proposes one of his own, the profoundness of which modern geologists are only beginning to appreciate. "It is not," he says, "because the lands covered by seas were originally at different altitudes, that the waters have risen, or subsided, or receded from some parts and inundated others. But the reason is, that the same land is sometimes raised up and sometimes depressed, and the sea also is simultaneously raised and depressed, so that it either overflows or returns into its own place again. We must therefore ascribe the cause to the ground, either to that ground which is under the sea, or to that which becomes flooded by it, but rather to that which lies beneath the sea, for this is more moveable, and, on account of its humidity, can be altered with greater celerity.* *It is proper,*" he observes in continuation, "*to derive our explanations from things which are obvious, and in some measure of daily occurrence, such as deluges, earthquakes, volcanic eruptions, and sudden swellings of the land beneath the sea; for the last raise up the sea also, and when the same lands subside again, they occasion the sea to be let down. And it is not merely the small, but the large islands also, and not merely the islands, but the continents, which can be lifted up together with the sea;*

* "Quod enim hoc attollitur aut subsidit, et vel inundat quædam loca, vel ab iis recedit, ejus rei causa non est, quod alia aliis sola humiliora sint aut altiora; sed quod idem solum modò attollitur modò deprimitur, simulque etiam modò attollitur modò deprimitur mare: itaque vel exundat vel in suum redit locum."

Postea, p. 88. "Restat, ut causam adscribamus solo, sive quod mari subest sive quod inundatur; potiùs tamen ei quod mari subest. Hoc enim multò est mobilius, et quod ob humiditatem celerius mutari possit." — Strabo, lib. ii.

and both large and small tracts may subside, for habitations and cities, like Bure, Bizona, and many others, have been engulfed by earthquakes."

In another place, this learned geographer, in alluding to the tradition that Sicily had been separated by a convulsion from Italy, remarks, that at present the land near the sea in those parts was rarely shaken by earthquakes, since there were now open orifices whereby fire and ignited matters and waters escape; but formerly, when the volcanos of Etna, the Lipari Islands, Ischia, and others, were closed up, the imprisoned fire and wind might have produced far more vehement movements.* The doctrine, therefore, that volcanos are safety-valves, and that the subterranean convulsions are probably most violent when first the volcanic energy shifts itself to a new quarter, is not modern.

We learn from a passage in Strabo†, that it was a dogma of the Gaulish Druids that the universe was immortal, but destined to survive catastrophes both of fire and water. That this doctrine was communicated to them from the East, with much of their learning, cannot be doubted. Cæsar‡, it will be remembered, says that they made use of Greek letters in arithmetical computations.

Pliny had no theoretical opinions of his own concerning changes of the earth's surface; and in this department, as in others, he restricted himself to the task of a compiler, without reasoning on the facts stated by him, or attempting to digest them into regular order. But his enumeration of the new islands which had been formed in the Mediterranean, and of

* Strabo, lib. vi. p. 396.

† Book iv.

‡ l. vi. ch. xiii.

other convulsions, shews that the ancients had not been inattentive observers of the changes which had taken place within the memory of man.

Such, then, appear to have been the opinions entertained before the Christian era, concerning the past revolutions of our globe. Although no particular investigations had been made for the express purpose of interpreting the monuments of ancient changes, they were too obvious to be entirely disregarded; and the observation of the present course of nature presented too many proofs of alterations continually in progress on the earth to allow philosophers to believe that nature was in a state of rest, or that the surface had remained, and would continue to remain, unaltered. But they had never compared attentively the results of the destroying and reproductive operations of modern times with those of remote eras, nor had they ever entertained so much as a conjecture concerning the comparative antiquity of the human race, or of living species of animals and plants, with those belonging to former conditions of the organic world. They had studied the movements and positions of the heavenly bodies with laborious industry, and made some progress in investigating the animal, vegetable, and mineral kingdoms; but the ancient history of the globe was to them a sealed book, and, although written in characters of the most striking and imposing kind, they were unconscious even of its existence.

CHAPTER III.

HISTORY OF THE PROGRESS OF GEOLOGY—*continued.*

Arabian writers of the tenth century — Avicenna — Omar — Cosmogony of the Koran — Kazwini — Early Italian writers — Fracastoro — Controversy as to the real nature of organized fossils — Fossil shells attributed to the Mosaic deluge — Palissy — Steno — Scilla — Quirini — Boyle — Lister — Leibnitz — Hooke's Theory of Elevation by Earthquakes — His speculations on lost species of animals — Ray — Physico-theological writers — Woodward's Diluvial Theory — Burnet — Whiston — Hutchinson — Vallisneri — Lazzaro Moro — Generelli — Buffon — His theory condemned by the Sorbonne as unorthodox — His declaration — Targioni — Arduino — Michell — Catcott — Raspe — Fuchsel — Fortis — Testa — Whitehurst — Pallas — Saussure.

Arabian writers.—AFTER the decline of the Roman empire, the cultivation of physical science was first revived with some success by the Saracens, about the middle of the eighth century of our era. The works of the most eminent classic writers were purchased at great expense from the Christians, and translated into Arabic; and Al Mamûn, son of the famous Harûn-al-Rashid, the contemporary of Charlemagne, received with marks of distinction, at his court at Bagdad, astronomers and men of learning from different countries. This caliph, and some of his successors, encountered much opposition and jealousy from the doctors of the Mahomedan law, who wished the Moslems to confine their studies to the Koran, dreading the effects of the diffusion of a taste for the physical sciences.*

* Mod. Univ. Hist. vol. ii. chap. iv. section iii.

Avicenna.—Almost all the works of the early Arabian writers are lost. Amongst those of the tenth century, of which fragments are now extant, is a short treatise “On the Formation and Classification of Minerals,” by Avicenna, a physician, in whose arrangement there is considerable merit. The second chapter, “On the Cause of Mountains,” is remarkable; for mountains, he says, are formed, some by essential, others by accidental causes. In illustration of the essential, he instances “a violent earthquake, by which land is elevated, and becomes a mountain;” of the accidental, the principal, he says, is excavation by water, whereby cavities are produced, and adjoining lands made to stand out and form eminences.*

Omar—Cosmogony of the Koran.—In the same century also, Omar, surnamed “El Aalem,” or “The Learned,” wrote a work on “The Retreat of the Sea.” It appears that on comparing the charts of his own time with those made by the Indian and Persian astronomers two thousand years before, he had satisfied himself that important changes had taken place since the times of history in the form of the coasts of Asia, and that the extension of the sea had been greater at some former periods. He was confirmed in this opinion by the numerous salt springs and marshes in the interior of Asia,—a phenomenon from which Pallas, in more recent times, has drawn the same inference.

Von Hoff has suggested, with great probability, that the changes in the level of the Caspian (some of

* Montes quándóque fiunt ex causa essentiali, quándóque ex causa accidentali. Ex essentiali causa, ut ex vehementi motu terræ elevatur terra, et fit mons. Accidentali, &c. — De Congelatione Lapidum, ed. Gedani, 1682.

which there is reason to believe have happened within the historical era), and the geological appearances in that district, indicating the desertion by that sea of its ancient bed, had probably led Omar to his theory of a general subsidence. But whatever may have been the proofs relied on, his system was declared contradictory to certain passages in the Koran, and he was called upon publicly to recant his errors; to avoid which persecution he went into voluntary banishment from Samarkand.*

The cosmological opinions expressed in the Koran are few, and merely introduced incidentally: so that it is not easy to understand how they could have interfered so seriously with free discussion on the former changes of the globe. The Prophet declares that the earth was created in two days, and the mountains were then placed on it; and during these, and two additional days, the inhabitants of the earth were formed; and in two more the seven heavens.†

* Von Hoff, *Geschichte der Veränderungen der Erdoberfläche*, vol. i. p. 406., who cites Delisle, *bey Hismann Welt-und Völkergeschichte*. *Alte Gesch.* 1^{ter} Theil. s. 234. — The Arabian persecutions for heretical dogmas in theology were often very sanguinary. In the same ages wherein learning was most in esteem, the Mahometans were divided into two sects, one of whom maintained that the Koran was increate, and had subsisted in the very essence of God from all eternity; and the other, the Motazalites, who, admitting that the Koran was instituted by God, conceived it to have been first made when revealed to the Prophet at Mecca, and accused their opponents of believing in two eternal beings. The opinions of each of these sects were taken up by different caliphs in succession, and the followers of each sometimes submitted to be beheaded, or flogged till at the point of death, rather than renounce their creed. — *Mod. Univ. Hist.* vol. ii. ch. iv.

† Koran, chap. xli.

There is no more detail of circumstances; and the deluge, which is also mentioned, is discussed with equal brevity. The waters are represented to have poured out of an oven; a strange fable, said to be borrowed from the Persian Magi, who represented them as issuing from the oven of an old woman.* All men were drowned, save Noah and his family; and then God said, “O earth, swallow up thy waters; and thou, O heaven, withhold thy rain;” and immediately the waters abated.†

We may suppose Omar to have represented the desertion of the land by the sea to have been gradual, and that his hypothesis required a greater lapse of ages than was consistent with Moslem orthodoxy; for it is to be inferred from the Koran, that man and this planet were created at the same time; and although Mahomet did not limit expressly the antiquity of the human race, yet he gave an implied sanction to the Mosaic chronology by the veneration expressed by him for the Hebrew Patriarchs.‡

A manuscript work, entitled the “Wonders of Nature,” is preserved in the Royal Library at Paris, by an Arabian writer, Mohammed Kazwini, who flourished in the seventh century of the Hegira, or at the close of the thirteenth century of our era.§ Besides several curious remarks on aerolites, earthquakes, and the successive changes of position which the land and

* Sale’s Koran, chap. xi. see note.

† Ibid.

‡ Kossa, appointed master to the Caliph Al Mamûd, was author of a book, entitled “The History of the Patriarchs and Prophets, from the Creation of the World.” — Mod. Univ. Hist. vol. ii. chap. iv.

§ Translated by MM. Chezy and De Sacy, and cited by M. E. de Beaumont, Ann. des Sci. Nat. 1832.

sea have undergone, we meet with the following beautiful passage, which is given as the narrative of Khidhz, an allegorical personage:—"I passed one day by a very ancient and wonderfully populous city, and asked one of its inhabitants how long it had been founded. 'It is indeed a mighty city,' replied he, 'we know not how long it has existed, and our ancestors were on this subject as ignorant as ourselves.' Five centuries afterwards, as I passed by the same place, I could not perceive the slightest vestige of the city. I demanded of a peasant who was gathering herbs, upon its former site, how long it had been destroyed. 'In sooth, a strange question!' replied he. 'The ground here has never been different from what you now behold it.'—'Was there not of old,' said I, 'a splendid city here?'—'Never,' answered he, 'so far as we have seen, and never did our fathers speak to us of any such.' On my return there, 500 years afterwards, *I found the sea in the same place*, and on its shores were a party of fishermen, of whom I inquired how long the land had been covered by the waters? 'Is this a question,' said they, 'for a man like you? this spot has always been what it is now.' I again returned, 500 years afterwards, and the sea had disappeared; I inquired of a man who stood alone upon the spot, how long ago this change had taken place, and he gave me the same answer as I had received before. Lastly, on coming back again after an equal lapse of time, I found there a flourishing city, more populous and more rich in beautiful buildings than the city I had seen the first time, and when I would fain have informed myself concerning its origin, the inhabitants answered me, 'Its rise is lost in remote antiquity: we are ignorant

how long it has existed, and our fathers were on this subject as ignorant as ourselves.’”

Early Italian writers—Fracastoro, 1517.—It was not till the earlier part of the sixteenth century that geological phenomena began to attract the attention of the Christian nations. At that period a very animated controversy sprung up in Italy, concerning the true nature and origin of marine shells, and other organized fossils, found abundantly in the strata of the peninsula.* The excavations made in 1517, for repairing the city of Verona, brought to light a multitude of curious petrifications, and furnished matter for speculation to different authors, and among the rest to Fracastoro†, who declared his opinion, that fossil shells had all belonged to living animals, which had formerly lived and multiplied where their exuviae are now found. He exposed the absurdity of having recourse to a certain “plastic force,” which it was said had power to fashion stones into organic forms; and, with no less cogent arguments, demonstrated the futility of attributing the situation of the shells in question to the Mosaic deluge, a theory obstinately defended by some. That inundation, he observed, was too transient, it consisted principally of fluviate waters; and if it had transported shells to great distances, must have strewed them over the surface, not buried them at vast depths in the interior of mountains. His clear exposition of the evidence would have terminated the discussion for ever, if the passions of mankind had not been enlisted in the

* See Brocchi’s Discourse on the Progress of the Study of Fossil Conchology in Italy, where some of the following notices on Italian writers will be found more at large.

† Museum Calceol.

dispute; and even though doubts should for a time have remained in some minds, they would speedily have been removed by the fresh information obtained almost immediately afterwards, respecting the structure of fossil remains, and of their living analogues.

But the clear and philosophical views of Fracastoro were disregarded, and the talent and argumentative powers of the learned were doomed for three centuries to be wasted in the discussion of these two simple and preliminary questions: first, whether fossil remains had ever belonged to living creatures; and, secondly, whether, if this be admitted, all the phenomena could be explained by the Noachian deluge. It had been the consistent belief of the Christian world down to the period now under consideration, that the origin of this planet was not more remote than a few thousand years; and that since the creation the deluge was the only great catastrophe by which considerable change had been wrought on the earth's surface. On the other hand, the opinion was scarcely less general, that the final dissolution of our system was an event to be looked for at no distant period. The era, it is true, of the expected millennium had passed away; and for five hundred years after the fatal hour, when the annihilation of the planet had been looked for, the monks remained in undisturbed enjoyment of rich grants of land bequeathed to them by pious donors, who, in the preamble of deeds beginning "*appropinquante mundi termino*"——"*appropinquante magno judicii die*," left lasting monuments of the popular delusion. *

* In the monasteries of Sicily, in particular, the title-deeds of many valuable grants of land are headed by such preambles, com-

But although in the sixteenth century it had become necessary to interpret the prophecies more liberally, and to assign a more distant date to the future conflagration of the world, we find, in the speculations of the early geologists, perpetual allusion to such an approaching catastrophe; while in all that regarded the antiquity of the earth, no modification whatever of the opinions of the dark ages had been effected. Considerable alarm was at first excited when the attempt was made to invalidate, by physical proofs, an article of faith so generally received; but there was sufficient spirit of toleration and candour amongst the Italian ecclesiastics, to allow the subject to be canvassed with much freedom. They entered warmly themselves into the controversy, often favouring different sides of the question; and however much we may deplore the loss of time and labour devoted to the defence of untenable positions, it must be conceded, that they displayed far less polemic bitterness than certain writers who followed them “beyond the Alps,” two centuries and a half later.

CONTROVERSY AS TO THE REAL NATURE OF FOSSIL ORGANIC REMAINS.

Mattioli—Falloppio.—The system of scholastic disputations encouraged in the Universities of the middle ages had unfortunately trained men to habits of indefinite argumentation, and they often preferred absurd and extravagant propositions, because greater skill was required to maintain them; the end and

posed by the testators about the period when the good King Roger was expelling the Saracens from that island.

object of such intellectual combats being victory and not truth. No theory could be so far-fetched or fantastical as not to attract some followers, provided it fell in with popular notions; and as cosmogonists were not at all restricted, in building their systems, to the agency of known causes, the opponents of Fracastoro met his arguments by feigning imaginary causes, which differed from each other rather in name than in substance. Andrea Mattioli, for instance, an eminent botanist, the illustrator of Dioscorides, embraced the notion of Agricola, a German miner, that a certain "materia pinguis," or "fatty matter," set into fermentation by heat, gave birth to fossil organic shapes. Yet Mattioli had come to the conclusion, from his own observations, that porous bodies, such as bones and shells, might be converted into stone, as being permeable to what he termed the "lapidifying juice." In like manner, Falloppio of Padua conceived that petrified shells had been generated by fermentation in the spots where they were found, or that they had in some cases acquired their form from "the tumultuous movements of terrestrial exhalations." Although a celebrated professor of anatomy, he taught that certain tusks of elephants dug up in his time at Puglia were mere earthy concretions, and, consistently with these principles, he even went so far as to consider it not improbable, that the vases of Monte Testaceo at Rome were natural impressions stamped in the soil.* In the same spirit, Mercati, who published, in 1574, faithful figures of the fossil shells preserved by Pope Sextus V. in the Museum of the Vatican, expressed an opinion that they were mere stones, which had assumed

* De Fossilib. pp. 109. and 176.

their peculiar configuration from the influence of the heavenly bodies ; and Olivi of Cremona, who described the fossil remains of a rich Museum at Verona, was satisfied with considering them mere "sports of nature."

Cardano, 1552.—The title of a work of Cardano's, published in 1552, "De Subtilitate" (corresponding to what would now be called Transcendental Philosophy), would lead us to expect, in the chapter on minerals, many far-fetched theories characteristic of that age ; but, when treating of petrified shells, he decided that they clearly indicated the former sojourn of the sea upon the mountains.*

Some of the fanciful notions of those times were deemed less unreasonable, as being somewhat in harmony with the Aristotelian theory of spontaneous generation, then taught in all the schools. For men who had been instructed in early youth, that a large proportion of living animals and plants were formed from the fortuitous concourse of atoms, or had sprung from the corruption of organic matter, might easily persuade themselves, that organic shapes, often imperfectly preserved in the interior of solid rocks, owed their existence to causes equally obscure and mysterious.

Cesalpino — *Majoli*, 1597. — But there were not wanting some, who, at the close of this century, expressed more sound and sober opinions. Cesalpino, a celebrated botanist, conceived that fossil shells had been left on the land by the retiring sea, and had concreted into stone during the consolidation of the soil † ; and, in the following year (1597), Simeone Majoli ‡ went still farther, and, coinciding for the most part

* Brocchi, Con. Foss. Subap. Disc. sui Prog. vol. i. p. 5.

† De Metallicis.

‡ Dies Caniculares.

with the views of Cesalpino, suggested that the shells and submarine matter of the Veronese, and other districts, might have been cast up upon the land, by volcanic explosions, like those which gave rise, in 1538, to Monte Nuovo, near Puzzuoli.—This hint was the first imperfect attempt to connect the position of fossil shells with the agency of volcanos, a system afterwards more fully developed by Hooke, Lazzaro Moro, Hutton, and other writers.

Two years afterwards, Imperati advocated the animal origin of fossilized shells, yet admitted that stones could vegetate by force of “an internal principle;” and, as evidence of this, he referred to the teeth of fish, and spines of echini found petrified.*

Palissy, 1580.—Palissy, a French writer on “The Origin of Springs from Rain-water,” and of other scientific works, undertook, in 1580, to combat the notions of many of his contemporaries in Italy, that petrified shells had all been deposited by the universal deluge. “He was the first,” said Fontenelle, when, in the French Academy, he pronounced his eulogy nearly a century and a half later, “who dared assert,” in Paris, that fossil remains of testacea and fish had once belonged to marine animals.

Fabio Colonna.—To enumerate the multitude of Italian writers, who advanced various hypotheses, all equally fantastical, in the early part of the seventeenth century, would be unprofitably tedious, but Fabio Colonna deserves to be distinguished; for, although he gave way to the dogma, that all fossil remains were to be referred to the Noachian deluge, he resisted the absurd theory of Stelluti, who taught that fossil wood

* *Storia Naturale*.

and ammonites were mere clay, altered into such forms by sulphureous waters and subterranean heat; and he pointed out the different states of shells buried in the strata, distinguishing between, first, the mere mould or impression; secondly, the cast or nucleus; and, thirdly, the remains of the shell itself. He had also the merit of being the first to point out, that some of the fossils had belonged to marine, and some to terrestrial, testacea.*

Steno, 1669.—But the most remarkable work of that period was published by Steno, a Dane, once professor of anatomy at Padua, and who afterwards resided many years at the court of the Grand Duke of Tuscany. His treatise bears the quaint title of “*De Solido intra Solidum naturaliter contento* (1669),” by which the author intended to express, “On Gems, Crystals, and organic Petrifications inclosed within solid Rocks.” This work attests the priority of the Italian school in geological research; exemplifying at the same time the powerful obstacles opposed, in that age, to the general reception of enlarged views in the science. It was still a favourite dogma that the fossil remains of shells and marine creatures were not of animal origin; an opinion adhered to by many from their extreme reluctance to believe, that the earth could have been inhabited by living beings before a great part of the existing mountains were formed. In reference to this controversy, Steno had dissected a shark recently taken from the Mediterranean, and had demonstrated that its teeth and bones were identical with many fossils found in Tuscany. He had also compared the shells discovered in the Italian strata

* Osserv. sugli Animali aquat. e terrest. 1626.

with living species, pointed out their resemblance, and traced the various gradations from shells merely calcined, or which had only lost their animal gluten, to those petrifications in which there was a perfect substitution of stony matter. In his division of mineral masses, he insisted on the secondary origin of those deposits in which the spoils of animals, or fragments of older rocks were inclosed. He distinguished between marine formations and those of a fluviate character, the last containing reeds, grasses, or the trunks and branches of trees. He argued in favour of the original horizontality of sedimentary deposits, attributing their present inclined and vertical position sometimes to the escape of subterranean vapours, heaving the crust of the earth from below upwards, and sometimes to the falling in of masses over-lying subterranean cavities.

He declared that he had obtained proof that Tuscany must successively have acquired six distinct configurations, having been twice covered by water, twice laid dry with a level, and twice with an irregular and uneven surface.* He displayed great anxiety to reconcile his new views with Scripture, for which purpose he pointed to certain rocks as having been formed before the existence of animals and plants; selecting unfortunately as examples certain formations of limestone and sandstone in his own country, now known to contain, though sparingly, the remains of animals and plants,—strata which do not even rank as the oldest part of our secondary series. Steno suggested that Moses, when speaking of the loftiest mountains as having been covered by the deluge, meant merely the loftiest of the hills then existing, which may not have been very high.

* Sex itaque distinctas Etruriæ facies agnoscimus, dum bis fluida, bis plana, et sicca, bis aspera fuerit, &c.

The diluvian waters, he supposed, may have issued from the interior of the earth into which they had retired, when in the beginning the land was separated from the sea. These, and other hypotheses on the same subject, are not calculated to enhance the value of the treatise, and could scarcely fail to detract from the authority of those opinions which were sound and legitimate deductions from fact and observation. They have served, nevertheless, as the germs of many popular theories of later times, and in an expanded form have been put forth as original inventions by some of our contemporaries.

Scilla, 1670.—Scilla, a Sicilian painter, published, in 1670, a work on the fossils of Calabria, illustrated by good engravings. This was written in Latin, with great spirit and elegance, and it proves the continued ascendancy of dogmas often refuted; for we find the wit and eloquence of the author chiefly directed against the obstinate incredulity of naturalists as to the organic nature of fossil shells.* Like many eminent naturalists of his day, Scilla gave way to the popular persuasion, that all fossil shells were the effects and proofs of the Mosaic deluge. It may be doubted whether he was perfectly sincere, and some of his contemporaries who took the same course were certainly not so. But so eager were they to root out what they justly considered an absurd prejudice respecting the nature of organized fossils, that they seem to have

* Scilla quotes the remark of Cicero on the story that a stone in Chios had been cleft open, and presented the head of Paniscus in relief: — “I believe,” said the orator, “that the figure bore some resemblance to Paniscus, but not such that you would have deemed it sculptured by Scopas; for chance never perfectly imitates the truth.”

been ready to make any concessions, in order to establish this preliminary point. Such a compromising policy was short-sighted, since it was to little purpose that the nature of the documents should at length be correctly understood, if men were to be prevented from deducing fair conclusions from them.

Diluvial Theory.—The theologians who now entered the field in Italy, Germany, France, and England, were innumerable; and henceforward, they who refused to subscribe to the position, that all marine organic remains were proofs of the Mosaic deluge, were exposed to the imputation of disbelieving the whole of the sacred writings. Scarcely any step had been made in approximating to sound theories since the time of Fracastoro, more than a hundred years having been lost, in writing down the dogma that organized fossils were mere sports of nature. An additional period of a century and a half was now destined to be consumed in exploding the hypothesis, that organized fossils had all been buried in the solid strata by the Noachian flood. Never did a theoretical fallacy, in any branch of science, interfere more seriously with accurate observation and the systematic classification of facts. In recent times, we may attribute our rapid progress chiefly to the careful determination of the order of succession in mineral masses, by means of their different organic contents, and their regular superposition. But the old diluvialists were induced by their system to confound all the groups of strata together instead of discriminating,—to refer all appearances to one cause and to one brief period, not to a variety of causes acting throughout a long succession of epochs. They saw the phenomena only as they desired to see them, sometimes misrepresenting facts,

and at other times deducing false conclusions from correct data. Under the influence of such prejudices, three centuries were of as little avail as a few years in our own times, when we are no longer required to propel the vessel against the force of an adverse current.

It may be well to forewarn the reader, that in tracing the history of geology from the close of the seventeenth to the end of the eighteenth century, he must expect to be occupied with accounts of the retardation, as well as of the advance of the science. It will be necessary to point out the frequent revival of exploded errors, and the relapse from sound to the most absurd opinions; and to dwell on futile reasoning and visionary hypothesis, because some of the most extravagant systems were invented or controverted by men of acknowledged talent. In short, a sketch of the progress of Geology is the history of a constant and violent struggle between new opinions and ancient doctrines, sanctioned by the implicit faith of many generations, and supposed to rest on scriptural authority. The inquiry, therefore, although highly interesting to one who studies the philosophy of the human mind, is too often barren of instruction to him who searches for truths in physical science.

Quirini, 1676. — Quirini, in 1676*, contended, in opposition to Scilla, that the diluvian waters could not have conveyed heavy bodies to the summit of mountains, since the agitation of the sea never (as Boyle had demonstrated) extended to great depths†; and

* *De Testaceis fossilibus Mus. Septaliani.*

† The opinions of Boyle, alluded to by Quirini, were published a few years before, in a short article entitled “On the Bottom of the Sea.” From observations collected from the divers of the pearl

still less could the testacea, as some pretended, have lived in these diluvian waters, for “the duration of the flood was brief, and *the heavy rains must have destroyed the saltness of the sea!*” He was the first writer who ventured to maintain that the universality of the Noachian cataclysm ought not to be insisted upon. As to the nature of petrified shells, he conceived that as earthy particles united in the sea to form the shells of mollusca, the same crystallizing process might be effected on the land; and that, in the latter case, the germs of the animals might have been disseminated through the substance of the rocks, and afterwards developed by virtue of humidity. Visionary as was this doctrine, it gained many proselytes even amongst the more sober reasoners of Italy and Germany; for it conceded both that fossil bodies were organic, and that the diluvial theory could not account for them.

Plot — Lister, 1678. — In the mean time, the doctrine that fossil shells had never belonged to real animals maintained its ground in England, where the agitation of the question began at a much later period. Dr. Plot, in his “Natural History of Oxfordshire” (1677), attributed to a “plastic virtue latent in the earth” the origin of fossil shells and fishes; and Lister, to his accurate account of British shells, in 1678, added the fossil species, under the appellation of

fishery, Boyle inferred that when the waves were six or seven feet high above the surface of the water, there were no signs of agitation at the depth of fifteen fathoms; and that even during heavy gales of wind, the motion of the water was exceedingly diminished at the depth of twelve or fifteen feet. He had also learnt from some of his informants, that there were currents running in opposite directions at different depths. — Boyle’s Works, vol. iii. p. 110. London, 1744.

turbinated and bivalve stones. “Either,” said he, “these were terrigenous, or, if otherwise, the animals they so exactly represent *have become extinct.*” This writer appears to have been the first who was aware of the continuity over large districts of the principal groups of strata in the British series, and who proposed the construction of regular geological maps.*

Leibnitz, 1680.—The great mathematician Leibnitz published his “*Protogœa*” in 1680. He imagined this planet to have been originally a burning luminous mass, which ever since its creation has been undergoing refrigeration. When the outer crust had cooled down sufficiently to allow the vapours to be condensed, they fell, and formed a universal ocean, covering the loftiest mountains, and investing the whole globe. The crust, as it consolidated from a state of fusion, assumed a vesicular and cavernous structure; and being rent in some places, allowed the water to rush into the subterranean hollows, whereby the level of the primeval ocean was lowered. The breaking in of these vast caverns is supposed to have given rise to the dislocated and deranged position of the strata “which Steno had described,” and the same disruptions communicated violent movements to the incumbent waters, whence great inundations ensued. The waters, after they had been thus agitated, deposited their sedimentary matter during intervals of quiescence, and hence the various stony and earthy strata. “We may recognize, therefore,” says Leibnitz, “a double origin of primitive masses, the one by refrigeration from igneous fusion, the other by concretion from aqueous

* See Mr. Conybeare’s excellent Introduction to the “*Outlines of the Geology of England and Wales,*” p. 12.

solution.” * By the repetition of similar causes (the disruption of the crust and consequent floods), alternations of new strata were produced, until at length these causes were reduced to a condition of quiescent equilibrium, and a more permanent state of things was established. †

Hooke, 1688. — The “Posthumous Works of Robert Hooke, M.D.,” well known as a great mathematician and natural philosopher, appeared in 1705, containing “A Discourse of Earthquakes,” which, we are informed by his editor, was written in 1668, but revised at subsequent periods. ‡ Hooke frequently refers to the best Italian and English authors who wrote before his time on geological subjects; but there are no passages in his works implying that he participated in the enlarged views of Steno and Lister, or of his contemporary, Woodward, in regard to the geographical extent of certain groups of strata. His treatise, however, is the most philosophical production of that age, in regard to the causes of former changes in the organic and inorganic kingdoms of nature.

“However trivial a thing,” he says, “a rotten shell may appear to some, yet these monuments of nature

* Unde jam duplex origo intelligitur primorum corporum, una, cum ab ignis fusione refrigescerent, altera, cum reconcrescerent ex solutione aquarum.

† Redeunte mox simili causâ strata subinde alia aliis imponebantur, et facies teneri adhuc orbis sæpius novata est. Donec quiescentibus causis, atque æquilibratis, consistentior emergeret rerum status. — For an able analysis of the views of Leibnitz, in his *Protogœa*, see Mr. Conybeare’s Report on the Progress of Geological Science, 1832.

‡ Between the year 1688 and his death, in 1703, he read several memoirs to the Royal Society, and delivered lectures on various subjects, relating to fossil remains and the effects of earthquakes.

are more certain tokens of antiquity than coins or medals, since the best of those may be counterfeited or made by art and design, as may also books, manuscripts, and inscriptions, as all the learned are now sufficiently satisfied has often been actually practised," &c.; "and though it must be granted that it is very difficult to read them (the records of nature) and *to raise a chronology out of them*, and to state the intervals of the time wherein such or such catastrophes and mutations have happened, yet it is not impossible." *

His theory of the extinction of Species.—Respecting the extinction of species, Hooke was aware that the fossil ammonites, nautili, and many other shells and fossil skeletons found in England, were of different species from any then known; but he doubted whether the species had become extinct, observing that the knowledge of naturalists of all the marine species, especially those inhabiting the deep sea, was very deficient. In some parts of his writings, however, he leans to the opinion that species had been lost; and, in speculating on this subject, he even suggests that there might be some connexion between the disappearance of certain kinds of animals and plants, and the changes wrought by earthquakes in former ages. Some species, he observes with great sagacity, are "*peculiar to certain places*, and not to be found elsewhere. If, then, such a place had been swallowed up, it is not improbable but that those animate beings may have been destroyed with it; and this may be true both of aërial and aquatic animals: for those animated bodies, whether vegetables or animals, which were

* Posth. Works, Lecture, Feb. 29. 1688.

naturally nourished or refreshed by the air, would be destroyed by the water *," &c. Turtles, he adds, and such large ammonites as are found in Portland, seem to have been the productions of hotter countries; and it is necessary to suppose that England once lay under the sea within the torrid zone! To explain this and similar phenomena, he indulges in a variety of speculations concerning changes in the position of the axis of the earth's rotation, "a shifting of the earth's centre of gravity, analogous to the revolutions of the magnetic pole," &c. None of these conjectures, however, are proposed dogmatically, but rather in the hope of promoting fresh inquiries and experiments.

In opposition to the prejudices of his age, we find him arguing against the idea that nature had formed fossil bodies "for no other end than to play the mimic in the mineral kingdom;" — maintaining that figured stones were "really the several bodies they represent, or the mouldings of them petrified," and "not, as some have imagined, a '*lusus naturæ*,' sporting herself in the needless formation of useless beings." †

* Posth. Works, p. 327.

† Posth. Works, Lecture, Feb. 15. 1688. Hooke explained, with considerable clearness, the different modes wherein organic substances may become lapidified; and, among other illustrations, he mentions some silicified palm-wood brought from Africa, on which M. de la Hire had read a Memoir to the Royal Academy of France, (June, 1692,) wherein he had pointed out not only the tubes running the length of the trunk, but the roots at one extremity. De la Hire, says Hooke, also treated of certain trees found petrified in "the river that passes by Bakan, in the kingdom of *Ava*, and which has for the space of ten leagues the virtue of petrifying wood." It is an interesting fact, that the silicified wood of the Irawadi should have attracted attention more than one hundred years ago. Remarkable discoveries have been recently

It was objected to Hooke, that his doctrine of the extinction of species derogated from the wisdom and power of the Omnipotent Creator ; but he answered, that, as individuals die, there may be some termination to the duration of a species ; and his opinions, he declared, were not repugnant to Holy Writ : for the Scriptures taught that our system was degenerating, and tending to its final dissolution ; “ and as, when that shall happen, all the species will be lost, why not some at one time and some at another ? ” *

His theory of the effects of earthquakes. — But his principal object was to account for the manner in which shells had been conveyed into the higher parts of “ the Alps, Apennines, and Pyrenean hills, and the interior of continents in general.” These and other appearances, he said, might have been brought about by earthquakes, “ which have turned plains into mountains, and mountains into plains, seas into land, and land into seas, made rivers where there were none before, and swallowed up others that formerly were, &c. &c. ; and which, since the creation of the world, have wrought many great changes on the superficial parts of the earth, and have been the instruments of placing shells, bones, plants, fishes, and the like, in those places where, with much astonishment, we find them.” † This doctrine, it is true, had been laid down in terms almost equally explicit by Strabo, to explain the occurrence of fossil shells in the interior of con-

made there of fossil animals and vegetables, by Mr. Crawford and Dr. Wallich. — See Geol. Trans. vol. ii. part iii. p. 377. second series. De la Hire cites Father Duchatz, in the second volume of “ Observations made in the Indies by the Jesuits.”

* Posth. Works, Lecture May 29. 1689. † Posth. Works, p. 312.

tinents, and to that geographer, and other writers of antiquity, Hooke frequently refers; but the revival and development of the system was an important step in the progress of modern science.

Hooke enumerated all the examples known to him of subterranean disturbance, from "the sad catastrophe of Sodom and Gomorrah" down to the Chilian earthquake of 1646. The elevating of the bottom of the sea, the sinking and submersion of the land, and most of the inequalities of the earth's surface, might, he said, be accounted for by the agency of these subterranean causes. He mentions that the coast near Naples *was raised during the eruption of Monte Nuovo*; and that, in 1591, land rose in the island of St. Michael, during an eruption; and although it would be more difficult, he says, to prove, he does not doubt but that there had been as many earthquakes in the parts of the earth under the ocean, as in the parts of the dry land; in confirmation of which, he mentions the immeasurable depth of the sea near some volcanos. To attest the extent of simultaneous subterranean movements, he refers to an earthquake in the West Indies, in the year 1690, where the space of earth raised, or "struck upwards," by the shock, exceeded, he affirms, the length of the Alps and the Pyrenees.

Hooke's diluvial theory.—As Hooke declared the favourite hypothesis of the day, "that marine fossil bodies were to be referred to Noah's flood," to be wholly untenable, he appears to have felt himself called upon to substitute a diluvial theory of his own, and thus he became involved in countless difficulties and contradictions. "During the great catastrophe," he said, "there might have been a changing of that part which was before dry land into sea by

sinking, and of that which was sea into dry land by raising, and marine bodies might have been buried in sediment beneath the ocean, in the interval between the creation and the deluge.”* Then follows a disquisition on the separation of the land from the waters, mentioned in Genesis : during which operation some places of the shell of the earth were forced outwards, and others pressed downwards or inwards, &c. His diluvial hypothesis very much resembled that of Steno, and was entirely opposed to the fundamental principles professed by him, that he would explain the former changes of the earth *in a more natural manner* than others had done. When, in despite of this declaration, he required a former “crisis of nature,” and taught that earthquakes had become debilitated, and that the Alps, Andes, and other chains, had been lifted up in a few months, his machinery became nearly as extravagant and visionary as that of his most fanciful predecessors ; and for this reason, perhaps, his whole theory of earthquakes met with undeserved neglect.

Ray, 1692.—One of his contemporaries, the celebrated naturalist, Ray, participated in the same desire to explain geological phenomena, by reference to causes less hypothetical than those usually resorted to.† In his essay on “Chaos and Creation,” he proposed a system, agreeing in its outline, and in many of its details, with that of Hooke ; but his knowledge of natural history enabled him to elucidate the subject

* *Posth. Works*, p. 410.

† Ray’s *Physico-theological Discourses* were of somewhat later date than Hooke’s great work on earthquakes. He speaks of Hooke as one “whom for his learning and deep insight into the mysteries of nature he deservedly honoured.”—*On the Deluge*, chap. iv.

with various original observations. Earthquakes, he suggested, might have been the second causes employed at the creation, in separating the land from the waters, and in gathering the waters together into one place. He mentions, like Hooke, the earthquake of 1646, which had violently shaken the Andes for some hundreds of leagues, and made many alterations therein. In assigning a cause for the general deluge, he preferred a change in the earth's centre of gravity to the introduction of earthquakes. Some unknown cause, he said, might have forced the subterranean waters outwards, as was, perhaps, indicated by "the breaking up of the fountains of the great deep."

Ray was one of the first of our writers who enlarged upon the effects of running water upon the land, and of the encroachment of the sea upon the shores. So important did he consider the agency of these causes, that he saw in them an indication of the tendency of our system to its final dissolution; and he wondered why the earth did not proceed more rapidly towards a general submersion beneath the sea, when so much matter was carried down by rivers, or undermined in the sea-cliffs. We perceive clearly from his writings, that the gradual decline of our system, and its future consummation by fire, was held to be as necessary an article of faith by the orthodox, as was the recent origin of our planet. His discourses, like those of Hooke, are highly interesting, as attesting the familiar association in the minds of philosophers, in the age of Newton, of questions in physics and divinity. Ray gave an unequivocal proof of the sincerity of his mind, by sacrificing his preferment in the church, rather than take an oath against the Covenanters, which he could not reconcile with his conscience. His reputation,

moreover, in the scientific world placed him high above the temptation of courting popularity, by pandering to the physico-theological taste of his age. It is, therefore, curious to meet with so many citations from the Christian fathers and prophets in his essays on physical science — to find him in one page proceeding, by the strict rules of induction, to explain the former changes of the globe, and in the next gravely entertaining the question, whether the sun and stars, and the whole heavens, shall be annihilated, together with the earth, at the era of the grand conflagration.

Woodward, 1695.—Among the contemporaries of Hooke and Ray, Woodward, a professor of medicine, had acquired the most extensive information respecting the geological structure of the crust of the earth. He had examined many parts of the British strata with minute attention; and his systematic collection of specimens, bequeathed to the University of Cambridge, and still preserved there as arranged by him, shows how far he had advanced in ascertaining the order of superposition. From the great number of facts collected by him, we might have expected his theoretical views to be more sound and enlarged than those of his contemporaries; but in his anxiety to accommodate all observed phenomena to the scriptural account of the Creation and Deluge, he arrived at most erroneous results. He conceived “the whole terrestrial globe to have been taken to pieces and dissolved at the flood, and the strata to have settled down from this promiscuous mass as any earthy sediment from a fluid.”* In corroboration of these views, he insisted upon the fact, that “marine bodies are lodged in the strata according

* *Essay towards a Natural History of the Earth*, 1695. Preface.

to the order of their gravity, the heavier shells in stone, the lighter in chalk, and so of the rest.”* Ray immediately exposed the unfounded nature of this assertion, remarking truly, that fossil bodies “are often mingled, heavy with light, in the same stratum;” and he even went so far as to say, that Woodward “must have invented the phenomena for the sake of confirming his bold and strange hypothesis†”—a strong expression from the pen of a contemporary.

Burnet, 1690.—At the same time Burnet published his “Theory of the Earth.”‡ The title is most characteristic of the age,—“The Sacred Theory of the Earth; containing an Account of the Original of the Earth, and of all the general Changes which it hath already undergone, or is to undergo, till the Consummation of all Things.” Even Milton had scarcely ventured in his poem to indulge his imagination so freely in painting scenes of the Creation and Deluge, Paradise and Chaos. He explained why the primeval earth enjoyed a perpetual spring before the flood! showed how the crust of the globe was fissured by “the sun’s rays,” so that it burst, and thus the diluvial waters were let loose from a supposed central abyss. Not satisfied with these themes, he derived from the books of the inspired writers, and even from heathen authorities, prophetic views of the future revolutions of the globe, gave a most terrific description of the general conflagration, and proved that a new heaven and a new earth will rise out of a *second chaos*—after which will follow the blessed millennium.

* Essay towards a Natural History of the Earth, 1695. Preface.

† Consequences of the Deluge, p. 165.

‡ First published in Latin between the years 1680 and 1690.

The reader should be informed, that, according to the opinion of many respectable writers of that age, there was good scriptural ground for presuming that the garden bestowed upon our first parents was not on the earth itself, but above the clouds, in the middle region between our planet and the moon. Burnet approaches with becoming gravity the discussion of so important a topic. He was willing to concede that the geographical position of Paradise was not in Mesopotamia, yet he maintained that it was upon the earth, and in the southern hemisphere, near the equinoctial line. Butler selected this conceit as a fair mark for his satire, when, amongst the numerous accomplishments of Hudibras, he says,—

He knew the seat of Paradise,
Could tell in what degree it lies ;
And, as he was disposed, could prove it
Below the moon, or else above it.

Yet the same monarch, who is said never to have slept without Butler's poem under his pillow, was so great an admirer and patron of Burnet's book, that he ordered it to be translated from the Latin into English. The style of the "Sacred Theory" was eloquent, and displayed powers of invention of no ordinary stamp. It was, in fact, a fine historical romance, as Buffon afterwards declared ; but it was treated as a work of profound science in the time of its author, and was panegyricized by Addison in a Latin ode, while Steele praised it in the "Spectator," and Warton, in his "Essay on Pope," discovered that Burnet united the faculty of *judgment* with powers of imagination.

Whiston, 1696.—Another production of the same school, and equally characteristic of the time, was that of Whiston, entitled, "A New Theory of the Earth ;

wherein the Creation of the World in Six Days, the Universal Deluge, and the General Conflagration, as laid down in the Holy Scriptures, are shewn to be perfectly agreeable to Reason and Philosophy." He was at first a follower of Burnet; but his faith in the infallibility of that writer was shaken by the declared opinion of Newton, that there was every presumption in astronomy against any former change in the inclination of the earth's axis. This was a leading dogma in Burnet's system, though not original, for it was borrowed from an Italian, Alessandro degli Alessandri, who had suggested it in the beginning of the fifteenth century, to account for the former occupation of the present continents by the sea. La Place has since strengthened the arguments of Newton, against the probability of any former revolution of this kind.

The remarkable comet of 1680 was fresh in the memory of every one when Whiston first began his cosmological studies, and the principal novelty of his speculations consisted in attributing the deluge to the near approach to the earth of one of these erratic bodies. Having ascribed an increase of the waters to this source, he adopted Woodward's theory, supposing all stratified deposits to have resulted from the "chaotic sediment of the flood." Whiston was one of the first who ventured to propose that the text of Genesis should be interpreted differently from its ordinary acceptation, so that the doctrine of the earth having existed long previous to the creation of man might no longer be regarded as unorthodox. He had the art to throw an air of plausibility over the most improbable parts of his theory, and seemed to be proceeding in the most sober manner, and by the aid of mathematical demonstration, to the establishment of his various

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propositions. Locke pronounced a panegyric on his theory, commending him for having explained so many wonderful and before inexplicable things. His book, as well as Burnet's, was attacked and refuted by Keill.* Like all who introduced purely hypothetical causes to account for natural phenomena, Whiston retarded the progress of truth, diverting men from the investigation of the laws of sublunary nature, and inducing them to waste time in speculations on the power of comets to drag the waters of the ocean over the land—on the condensation of the vapours of their tails into water, and other matters equally edifying.

Hutchinson, 1724.—John Hutchinson, who had been employed by Woodward in making his collection of fossils, published afterwards, in 1724, the first part of his “Moses's Principia,” wherein he ridiculed Woodward's hypothesis. He and his numerous followers were accustomed to declaim loudly against human learning; and they maintained that the Hebrew scriptures, when rightly translated, comprised a perfect system of natural philosophy, for which reason they objected to the Newtonian theory of gravitation.

Celsius.—Andrea Celsius, the Swedish astronomer, published about this time his remarks on the gradual diminution of the waters in the Baltic, to which I shall have occasion to advert more particularly in the sequel.†

Scheuchzer, 1708.—In Germany, in the mean time, Scheuchzer laboured to prove, in a work entitled “The Complaint of the Fishes” (1708), that the earth had been remodelled at the deluge. Pluche also, in 1732, wrote to the same effect; while Holbach, in 1753, after

* An Examination of Dr. Burnet's Theory, &c. 2d ed. 1734.

† Book ii. ch. 4.

considering the various attempts to refer all the ancient formations to the Noachian flood, exposed the inadequacy of this cause.

Italian Geologists—Vallisneri.—It is with pleasure that I return to the geologists of Italy, who preceded, as has been already shewn, the naturalists of other countries in their investigations into the ancient history of the earth, and who still maintained a decided preeminence. They refuted and ridiculed the physico-theological systems of Burnet, Whiston, and Woodward*; while Vallisneri†, in his comments on the Woodwardian theory, remarked how much the interests of religion, as well as those of sound philosophy, had suffered by perpetually mixing up the sacred writings with questions in physical science. The works of this author were rich in original observations. He attempted the first general sketch of the marine deposits of Italy, their geographical extent, and most characteristic organic remains. In his treatise “On the Origin of Springs,” he explained their dependence on the order and often on the dislocations of the strata, and reasoned philosophically against the opinions of those who regarded the disordered state of the earth’s crust as exhibiting signs of the wrath of God for the sins of man. He found himself under the necessity of contending, in his preliminary chapter, against St. Jerome, and four other principal interpreters of Scripture, besides several professors of divinity, “that springs

* Ramazzini even asserted, that the ideas of Burnet were mainly borrowed from a dialogue of one Patrizio; but Brocchi, after reading that dialogue, assures us, that there was scarcely any other correspondence between these systems, except that both were equally whimsical.

† *Dei Corpi Marini, Lettere critiche, &c.* 1721.

did not flow by subterranean siphons and cavities from the sea upwards, losing their saltness in the passage," for this theory had been made to rest on the infallible testimony of Holy Writ.

Although reluctant to generalise on the rich materials accumulated in his travels, Vallisneri had been so much struck with the remarkable continuity of the more recent marine strata, from one end of Italy to the other, that he came to the conclusion that the ocean formerly extended over the whole earth, and after abiding there for a long time, had gradually subsided. This opinion, however untenable, was a great step beyond Woodward's diluvian hypothesis, against which Vallisneri, and after him all the Tuscan geologists, uniformly contended, while it was warmly supported by the members of the Institute of Bologna.*

Among others of that day, Spada, a priest of Grezzana, in 1737, wrote to prove that the petrified marine bodies near Verona were not diluvian.† Mattani drew a similar inference from the shells of Volterra and other places; while Costantini, on the other hand, whose observations on the valley of the Brenta and other districts were not without value, undertook to vindicate the truth of the deluge, as also to prove that Italy had been peopled by the descendants of Japhet.‡

Moro, 1740.—Lazzaro Moro, in his work (published in 1740) "On the Marine Bodies which are found in the Mountains§," attempted to apply the theory of earthquakes, as expounded by Strabo, Pliny, and other ancient authors, with whom he was familiar, to the geological phenomena described by Vallisneri.||

* Brocchi, p. 28.

† Ibid. p. 33.

‡ Ibid. p. 37.

§ Sui Crostacei ed altri Corpi Marini che si trovano sui Monti.

|| Moro does not cite the works of Hooke and Ray; and al-

His attention was awakened to the elevating power of subterranean forces by a remarkable phenomenon which happened in his own time, and which had also been noticed by Vallisneri in his letters. A new island rose in 1707 from a deep part of the sea near Santorino in the Mediterranean, during continued shocks of an earthquake, and, increasing rapidly in size, grew in less than a month to be half a mile in circumference, and about twenty-five feet above high-water mark. It was soon afterwards covered by volcanic ejections, but, when first examined, it was found to be a white rock, bearing on its surface living oysters and crustacea. In order to ridicule the various theories then in vogue, Moro ingeniously supposes the arrival on this new isle of a party of naturalists ignorant of its recent origin. One immediately points to the marine shells, as proofs of the universal deluge; another argues that they demonstrate the former residence of the sea upon the mountains; a third dismisses them as mere *sports of nature*; while a fourth affirms, that they were born and nourished within the rock in ancient caverns, into which salt water had been raised in the shape of vapour by the action of subterranean heat.

Moro pointed with great judgment to the *faults* and dislocations of the strata described by Vallisneri, in the Alps and other chains, in confirmation of his doctrine, that the continents had been heaved up by

though so many of his views were in accordance with theirs, he was probably ignorant of their writings, for they had not been translated. As he always refers to the Latin edition of Burnet, and a French translation of Woodward, we may presume that he did not read English.

subterranean movements. He objected, on solid grounds, to the hypotheses of Burnet and of Woodward; yet he ventured so far to disregard the protest of Vallisneri, as to undertake the adaptation of every part of his own system to the Mosaic account of the creation. On the third day, he said, the globe was every where covered to the same depth by fresh water; and when it pleased the Supreme Being that the dry land should appear, volcanic explosions broke up the smooth and regular surface of the earth composed of primary rocks. These rose in mountain masses above the waves, and allowed melted metals and salts to ascend through fissures. The sea gradually acquired its saltness from volcanic exhalations, and, while it became more circumscribed in area, increased in depth. Sand and ashes ejected by volcanos were regularly disposed along the bottom of the ocean, and formed the secondary strata, which in their turn were lifted up by earthquakes. We need not follow this author in tracing the progress of the creation of vegetables and animals, on the other days of creation; but, upon the whole, it may be remarked, that few of the old cosmological theories had been conceived with so little violation of known analogies.

Generelli's illustrations of Moro, 1749.—The style of Moro was extremely prolix, and, like Hutton, who, at a later period, advanced many of the same views, he stood in need of an illustrator. The Scotch geologist was not more fortunate in the advocacy of Playfair, than was Moro in numbering amongst his admirers Cirillo Generelli, who, nine years afterwards, delivered at a sitting of Academicians at Cremona a spirited exposition of his theory. This learned Carmelitan friar does not pretend to have been an original observer,

but he had studied sufficiently to enable him to confirm the opinions of Moro by arguments from other writers ; and his selection of the doctrines then best established is so judicious, that a brief abstract of them cannot fail to be acceptable, as illustrating the state of geology in Europe, and in Italy in particular, before the middle of the last century.

The bowels of the earth, says he, have carefully preserved the memorials of past events, and this truth the marine productions so frequent in the hills attest. From the reflections of Lazzaro Moro, we may assure ourselves that these are the effects of earthquakes in past times, which have changed vast spaces of sea into terra firma, and inhabited lands into seas. In this, more than in any other department of physics, are observations and experiments indispensable, and we must diligently consider facts. The land is known, wherever we make excavations, to be composed of different strata or soils placed one above the other, some of sand, some of rock, some of chalk, others of marl, coal, pumice, gypsum, lime, and the rest. These ingredients are sometimes pure, and sometimes confusedly intermixed. Within are often imprisoned different marine fishes, like dried mummies, and more frequently shells, crustacea, corals, plants, &c. not only in Italy, but in France, Germany, England, Africa, Asia, and America. Sometimes in the lowest, sometimes in the loftiest beds of the earth, some upon the mountains, some in deep mines, others near the sea, and others hundreds of miles distant from it. But there are, in some districts, rocks wherein no marine bodies are found. The remains of animals consist chiefly of their more solid parts, and the most rocky strata must have been soft when such exuviæ

were inclosed in them. Vegetable productions are found in different states of maturity, indicating that they were imbedded in different seasons. Elephants, elks, and other terrestrial quadrupeds, have been found in England and elsewhere, in superficial strata, never covered by the sea. Alternations are rare, yet not without example, of marine strata, and those which contain marshy and terrestrial productions. Marine animals are arranged in the subterraneous beds with admirable order, in distinct groups, oysters here, dentalia or corals there, &c. as now, according to Marsilli*, on the shores of the Adriatic. We must abandon the doctrine, once so popular, which denies that organized fossils were derived from living beings, and we cannot account for their present position by the ancient theory of Strato, nor by that of Leibnitz, nor by the universal deluge, as explained by Woodward and others; "nor is it reasonable to call the Deity capriciously upon the stage, and to make him work miracles for the sake of confirming our preconceived hypotheses." — "I hold in utter abomination, most learned Academicians! those systems which are built with their foundations in the air, and cannot be propped up without a miracle; and I undertake, with the assistance of Moro, to explain to you, how these marine animals were transported into the mountains by natural causes."†

A brief abstract then follows of Moro's theory, by which, says Generelli, we may explain all the phe-

* Saggio fisico intorno alla Storia del Mare, part i. p. 24.

† Abbomino al sommo qualsivoglia sistema, che sia di pianta fabbricato in aria; massime quando è tale, che non possa sostenersi senza un miracolo, &c. — De' Crostacei e di altre Produz. del Mare, &c. 1749.

nomena, as Vallisneri so ardently desired, "*without violence, without fictions, without hypotheses, without miracles.*"* The Carmelitan then proceeds to struggle against an obvious objection to Moro's system, considered as a method of explaining the revolutions of the earth, *naturally*. If earthquakes have been the agents of such mighty changes, how does it happen that their effects since the times of history have been so inconsiderable? This same difficulty had, as we have seen, presented itself to Hooke, half a century before, and forced him to resort to a former "crisis of nature:" but Generelli defended his position by shewing how numerous were the accounts of eruptions and earthquakes, of new islands, and of elevations and subsidences of land, and yet how much greater a number of like events must have been unattested and unrecorded during the last six thousand years. He also appealed to Vallisneri as an authority to prove that the mineral masses containing shells bore, upon the whole, but a small proportion to those rocks which were destitute of organic remains; and the latter, says the learned monk, might have been created as they now exist, *in the beginning*.

Generelli then describes the continual waste of mountains and continents, by the action of rivers and torrents, and concludes with these eloquent and original observations:—"Is it possible that this waste should have continued for six thousand, and *perhaps* a greater number of years, and that the mountains should remain so great, unless their ruins have been repaired? Is it credible that the Author of Nature should have founded the world upon such laws, as that the dry land should

* "Senza violenze, senza finzioni, senza supposti, senza miracoli." De' Crostacei e di altre Produz. del Mare, &c. 1749.

for ever be growing smaller, and at last become wholly submerged beneath the waters? Is it credible that, amid so many created things, the mountains alone should daily diminish in number and bulk, without there being any repair of their losses? This would be contrary to that order of Providence which is seen to reign in all other things in the universe. Wherefore I deem it just to conclude, that the same cause which, in the beginning of time, raised mountains from the abyss, has, down to the present day, continued to produce others, in order to restore from time to time the losses of all such as sink down in different places, or are rent asunder, or in other way suffer disintegration. If this be admitted, we can easily understand why there should now be found upon many mountains so great a number of crustacea and other marine animals."

The reader will remark, that although this admirable essay embraces so large a portion of the principal objects of geological research, it makes no allusion to the extinction of certain classes of animals; and it is evident that no opinions on this head had, at that time, gained a firm footing in Italy. That Lister and other English naturalists should long before have declared in favour of the loss of species, while Scilla and most of his countrymen hesitated, was perhaps natural, since the Italian museums were filled with fossil shells belonging to species of which a great portion did actually exist in the Mediterranean; whereas the English collectors could obtain no recent species from such of their own strata as were then explored.

The weakest point in Moro's system consisted in deriving *all* the stratified rocks from volcanic ejections; an absurdity which his opponents took care to expose,

especially Vito Amici.* Moro seems to have been misled by his anxious desire to represent the formation of secondary rocks as having occupied an extremely short period, while at the same time he wished to employ known agents in nature. To imagine torrents, rivers, currents, partial floods, and all the operations of moving water, to have gone on exerting an energy many thousand times greater than at present, would have appeared preposterous and incredible, and would have required a hundred violent hypotheses; but we are so unacquainted with the true sources of subterranean disturbances, that their former violence may in theory be multiplied indefinitely, without its being possible to prove the same manifest contradiction or absurdity in the conjecture. For this reason, perhaps, Moro preferred to derive the materials of the strata from volcanic ejections, rather than from transportation by running water.

Marsilli.—Marsilli, in the work above alluded to by Generelli, had been prompted to institute inquiries into the bed of the Adriatic, by discovering, in the territory of Parma, (what Spada had observed near Verona, and Schiavo in Sicily,) that fossil shells were not scattered through the rocks at random, but disposed in regular order, according to certain genera and species.

Vitaliano Donati, 1750.—But with a view of throwing further light upon these questions, Donati, in 1750, undertook a more extensive investigation of the Adriatic, and discovered, by numerous soundings, that deposits of sand, marl, and tufaceous incrustations, most strictly analogous to those of the Subapennine hills,

* Sui Testacei della Sicilia.

were in the act of accumulating there. He ascertained that there were no shells in some of the submarine tracts, while in other places they lived together in families, particularly the genera *Arca*, *Pecten*, *Venus*, *Murex*, and some others. He also states that in divers localities he found a mass composed of corals, shells, and crustaceous bodies of different species, confusedly blended with earth, sand, and gravel. At the depth of a foot or more, the organic substances were entirely petrified and reduced to marble; at less than a foot from the surface, they approached nearer to their natural state; while at the surface they were alive, or if dead, in a good state of preservation.

Baldassari.—A contemporary naturalist, Baldassari, had shown that the organic remains in the tertiary marls of the Siennese territory were grouped in families, in a manner precisely similar to that above alluded to by Donati.

Buffon, 1749.—Buffon first made known his theoretical views concerning the former changes of the earth in his *Natural History*, published in 1749. He adopted the theory of an original volcanic nucleus, together with the universal ocean of Leibnitz. By this aqueous envelope the highest mountains were once covered. Marine currents then acted violently, and formed horizontal strata, by washing away solid matter in some parts, and depositing it in others; they also excavated deep submarine valleys. The level of the ocean was then depressed by the entrance of a part of its waters into subterranean caverns, and thus some land was left dry. Buffon seems not to have profited, like Leibnitz and Moro, by the observations of Steno, or he could not have imagined that the strata were generally horizontal, and that those which contain

organic remains had never been disturbed since the era of their formation. He was conscious of the great power annually exerted by rivers and marine currents in transporting earthy materials to lower levels, and he even contemplated the period when they would destroy all the present continents. Although in geology he was not an original observer, his genius enabled him to render his hypothesis attractive ; and by the eloquence of his style, and the boldness of his speculations, he awakened curiosity, and provoked a spirit of inquiry amongst his countrymen.

Soon after the publication of his "Natural History," in which was included his "Theory of the Earth," he received an official letter (dated January, 1751), from the Sorbonne, or Faculty of Theology in Paris, informing him that fourteen propositions in his works "were reprehensible and contrary to the creed of the church." The first of these obnoxious passages, and the only one relating to geology, was as follows :—"The waters of the sea have produced the mountains and valleys of the land—the waters of the heavens, reducing all to a level, will at last deliver the whole land over to the sea, and the sea, successively prevailing over the land, will leave dry new continents like those which we inhabit." Buffon was invited by the College, in very courteous terms, to send in an explanation, or rather a recantation, of his unorthodox opinions. To this he submitted ; and a general assembly of the Faculty having approved of his "Declaration," he was required to publish it in his next work. The document begins with these words :—"I declare that I had no intention to contradict the text of Scripture ; that I believe most firmly all therein related about the creation, both as to order of time and matter of fact ; and *I abandon every thing*

*in my book respecting the formation of the earth, and, generally, all which may be contrary to the narration of Moses.**

The grand principle which Buffon was called upon to renounce was simply this,—“that the present mountains and valleys of the earth are due to secondary causes, and that the same causes will in time destroy all the continents, hills, and valleys, and reproduce others like them.” Now, whatever may be the defects of many of his views, it is no longer controverted that the present continents are of secondary origin. The doctrine is as firmly established as the earth’s rotation on its axis; and that the land now elevated above the level of the sea will not endure for ever, is an opinion which gains ground daily, in proportion as we enlarge our experience of the changes now in progress.

Targioni, 1751.—Targioni, in his voluminous “Travels in Tuscany, 1751 and 1754,” laboured to fill up the sketch of the geology of that region left by Steno sixty years before. Notwithstanding a want of arrangement and condensation in his memoirs, they contained a rich store of faithful observations. He has not indulged in many general views, but in regard to the origin of valleys he was opposed to the theory of Buffon, who attributed them principally to submarine currents. The Tuscan naturalist laboured to show that both the larger and smaller valleys of the Apennines were excavated by rivers and floods, caused by the bursting of the barriers of lakes, after the retreat of the ocean. He also maintained that the elephants and other quadrupeds, so frequent in the lacustrine and alluvial deposits of Italy, had inhabited that

* Hist. Nat. tom. v. éd. de l’Imp. Royale, Paris, 1769,

peninsula ; and had not been transported thither, as some had conceived, by Hannibal or the Romans, nor by what they were pleased to term “ a catastrophe of nature.”

Lehman, 1756.—In the year 1756 the treatise of Lehman *, a German mineralogist, and director of the Prussian mines, appeared, who also divided mountains into three classes : the first, those formed with the world, and prior to the creation of animals, and which contained no fragments of other rocks ; the second class, those which resulted from the partial destruction of the primary rocks by a general revolution ; and a third class, resulting from local revolutions, and in part from the Noachian deluge.

A French translation of this work appeared in 1759, in the preface of which the translator displays very enlightened views respecting the operations of earthquakes, as well as of the aqueous causes.

Gesner, 1758.—In this year Gesner the botanist, of Zurich, published an excellent treatise on petrifications, and the changes of the earth which they testify.† After a detailed enumeration of the various classes of fossils of the animal and vegetable kingdoms, and remarks on the different states in which they are found petrified, he considers the geological phenomena connected with them ; observing, that some, like those of Eningen, resembled the testacea, fish, and plants indigenous in the neighbouring region‡ ; while some, such as ammonites, gryphites, belemnites, and other shells, are either of unknown species, or found only in the Indian and other distant seas. In order to

* Essai d'une Hist. Nat. des Couches de la Terre, 1759.

† John Gesner published at Leyden, in Latin.

‡ Part ii. chap. 9.

elucidate the structure of the earth, he gives sections, from Verenius, Buffon, and others, obtained in digging wells; distinguishes between horizontal and inclined strata; and, in speculating on the causes of these appearances, mentions Donati's examination of the bed of the Adriatic; the filling up of lakes and seas by sediment; the imbedding of shells, now in progress; and many known effects of earthquakes, such as the sinking down of districts, or the heaving up of the bed of the sea, so as to form new islands and lay dry strata containing petrifications. The ocean, he says, deserts its shores in many countries, as on the borders of the Baltic; but the rate of recession has been so slow in the last 2000 years, that to allow the Apennines, whose summits are filled with marine shells, to emerge to their present height would have required about 80,000 years,—a lapse of time ten times greater, or more, than the age of the universe. We must therefore refer the phenomenon to the command of the Deity, related by Moses, that the waters should be gathered together in one place, and the dry land appear." Gesner adopted the views of Leibnitz to account for the retreat of the primeval ocean: his essay displays much erudition; and the opinions of preceding writers of Italy, Germany, and England are commented upon with fairness and discrimination.

Arduino, 1759.—In the year following, Arduino*, in his memoirs on the mountains of Padua, Vicenza, and Verona, deduced, from original observations, the distinction of rocks into primary, secondary, and tertiary, and showed that in those districts there had been a succession of submarine volcanic eruptions.

* *Giornale del Grisellini*, 1759.

Michell, 1760.—In the following year (1760) the Rev. John Michell, Woodwardian Professor of Mineralogy at Cambridge, published, in the Philosophical Transactions, an Essay on the Cause and Phenomena of Earthquakes.* His attention had been drawn to this subject by the great earthquake of Lisbon in 1755. He advanced many original and philosophical views respecting the propagation of subterranean movements, and the caverns and fissures wherein steam might be generated. In order to point out the application of his theory to the structure of the globe, he was led to describe the arrangement and disturbance of the strata, their usual horizontality in low countries, and their contortions and fractured state in the neighbourhood of mountain chains. He also explained, with surprising accuracy, the relations of the central ridges of older rocks to the “long narrow slips of similar earths, stones, and minerals,” which are parallel to these ridges. In his generalizations, derived in great part from his own observations on the geological structure of Yorkshire, he anticipated many of the views more fully developed by later naturalists.

Catcott, 1761.—Michell's papers were entirely free from all physico-theological disquisitions, but some of his contemporaries were still earnestly engaged in defending or impugning the Woodwardian hypothesis.

* See a sketch of the History of English Geology, by Dr. Fitton. in Edinb. Rev. Feb. 1818, re-edited Lond. and Edinb. Phil. Mag. vol. i. and ii. 1832-33. Some of Michell's Observations anticipate in so remarkable a manner the theories established forty years afterwards, that his writings would probably have formed an era in the science, if his researches had been uninterrupted. He held, however, his professorship only eight years, when he succeeded to a benefice, and from that time he appears to have entirely discontinued his scientific pursuits.

We find many of these writings referred to by Catcott, an Hutchinsonian, who published a “Treatise on the Deluge” in 1761. He laboured particularly to refute an explanation offered by his contemporary, Bishop Clayton, of the Mosaic writings. That prelate had declared that the deluge “could not be literally true, save in respect to that part where Noah lived before the flood.” Catcott insisted on the universality of the deluge, and referred to traditions of inundations mentioned by ancient writers, or by travellers in the East Indies, China, South America, and other countries. This part of his book is valuable, although it is not easy to see what bearing the traditions have, if admitted to be authentic, on the Bishop’s argument; since no evidence is adduced to prove that the catastrophes were contemporaneous events, while some of them are expressly represented by ancient authors to have occurred in succession.

Fortis—Odoardi, 1761.—The doctrines of Arduino, above adverted to, were afterwards confirmed by Fortis and Desmarest, in their travels in the same country; and they, as well as Baldassari, laboured to complete the history of the Subapennine strata. In the work of Odoardi*, there was also a clear argument in favour of the distinct ages of the older Apennine strata, and the Subapennine formations of more recent origin. He pointed out that the strata of these two groups were *unconformable*, and must have been the deposits of different seas at distant periods of time.

Raspe, 1763.—A history of the new islands by Raspe, an Hanoverian, appeared in 1763, in Latin.†

* *Sui Corpi Marini del Feltrino*, 1761.

† *De Novis e Mari Natis Insulis*. Raspe was also the editor of the “Philosophical Works of Leibnitz. Amst. et Leipzig,

In this work, all the authentic accounts of earthquakes which had produced permanent changes on the solid parts of the earth were collected together and examined with judicious criticism. The best systems which had been proposed concerning the ancient history of the globe, both by ancient and modern writers, are reviewed; and the merits and defects of the doctrines of Hooke, Ray, Moro, Buffon, and others, fairly estimated. Great admiration is expressed for the hypothesis of Hooke, and his explanation of the origin of the strata is shown to have been more correct than Moro's, while their theory of the effects of earthquakes was the same. Raspe had not seen Michell's memoir, and his views concerning the geological structure of the earth were perhaps less enlarged; yet he was able to add many additional arguments in favour of Hooke's theory, and to render it, as he said, a nearer approach to what Hooke would have written had he lived in later times. As to the periods wherein all the earthquakes happened, to which we owe the elevation of various parts of our continents and islands, Raspe says he pretends not to assign their duration, still less to defend Hooke's suggestion, that the convulsions almost all took place during the Noachian deluge. He adverts to the apparent indications of the former tropical heat of the climate of Europe, and the changes in the species of animals and plants, as among the most obscure and difficult problems in geology. In regard to the islands raised from the sea, within the times of history or tradition, he declares that some of them were composed of strata containing organic

1765;" also author of "Tassie's Gems," and "Baron Munchausen's Travels."

remains, and that they were not, as Buffon had asserted, made of mere volcanic matter. His work concludes with an eloquent exhortation to naturalists to examine the isles which rose, in 1707, in the Grecian Archipelago, and, in 1720, in the Azores, and not to neglect such splendid opportunities of studying nature “in the act of parturition.” That Hooke’s writings should have been neglected for more than half a century, was matter of astonishment to Raspe; but it is still more wonderful that his own luminous exposition of that theory should, for more than another half century, have excited so little interest.

Fuchsel, 1762 and 1775.—Fuchsel, a German physician, published, in 1762, a geological description of the country between the Thuringerwald and the Hartz, and a memoir on the environs of Rudelstadt*; and afterwards, in 1773, a theoretical work on the ancient history of the earth and of man.† He had evidently advanced considerably beyond his predecessor Lehman, and was aware of the distinctness, both as to position and fossil contents, of several groups of strata of different ages, corresponding to the secondary formations now recognized by geologists in various parts of Germany. He supposed the European continents to have remained covered by the sea until the formation of the marine strata called in Germany “*muschelkalk*,” at the same time that the terrestrial plants of many European deposits attested the existence of dry land which bordered the ancient sea; land which, therefore, must have occupied the place of the present ocean. This

* *Acta Academiæ Electoralis Maguntinæ*, vol. ii. Erfurt.

† This account of Fuchsel is derived from an excellent analysis of his memoirs by M. Keferstein. *Journ. de Géologie*, tom. ii. Oct. 1830.

pre-existing continent had been *gradually* swallowed up by the sea, different parts having subsided in succession into subterranean caverns. All the sedimentary strata were originally horizontal, and their present state of derangement must be referred to subsequent oscillations of the ground.

As there were plants and animals in the ancient periods, so also there must have been men, but they did not all descend from one pair, but were created at various points on the earth's surface; and the number of these distinct birth-places was as great as are the original languages of nations.

In the writings of Fuchsel we see a strong desire manifested to explain geological phenomena as far as possible by reference to the agency of known causes; and although some of his speculations were fanciful, his views coincide much more nearly with those now generally adopted, than the theories afterwards promulgated by Werner and his followers.

Brander, 1766.—Gustavus Brander published, in 1766, his "*Fossilia Hantoniensia*," containing excellent figures of fossil shells from the more modern marine strata of our island. "Various opinions," he says in the preface, "had been entertained concerning the time when and how these bodies became deposited. Some there are, who conceive that it might have been effected in a wonderful length of time by a gradual changing and shifting of the sea," &c. But the most common cause assigned is that of "the deluge." This conjecture, he says, even if the universality of the flood be not called in question, is purely hypothetical. In his opinion, fossil animals and testacea were, for the most part, of unknown species; and of such as were known, the living analogues now belonged to southern latitudes.

Soldani, 1780.—Soldani* applied successfully his knowledge of zoology to illustrate the history of stratified masses. He explained that microscopic testacea and zoophytes inhabited the depths of the Mediterranean; and that the fossil species were, in like manner, found in those deposits wherein the fineness of their particles, and the absence of pebbles, implied that they were accumulated in a deep sea, or far from shore. This author first remarked the alternation of marine and fresh-water strata in the Paris basin.

Fortis—Testa, 1793.—A lively controversy arose between Fortis and another Italian naturalist, Testa, concerning the fish of Monte Bolca, in 1793. Their letters†, written with great spirit and elegance, show that they were aware that a large proportion of the Subapennine shells were identical with living species, and some of them with species now living in the torrid zone. Fortis proposed a somewhat fanciful conjecture, that when the volcanos of the Vicentin were burning, the waters of the Adriatic had a higher temperature; and in this manner, he said, the shells of warmer regions may once have peopled their own seas. But Testa was disposed to think that these species of testacea were still common to their own and to equinoctial seas: for many, he said, once supposed to be confined to hotter regions, had been afterwards discovered in the Mediterranean.‡

* *Saggio orittografico*, &c. 1780, and other Works.

† *Lett. sui Pesci Fossili di Bolca*. Milan, 1793.

‡ This argument of Testa has been strengthened of late years by the discovery, that dealers in shells had long been in the habit of selling Mediterranean species as shells of more southern and distant latitudes, for the sake of enhancing their price. It appears, moreover, from several hundred experiments made by that dis-

Cortesi—Spallanzani—Wallerius—Whitehurst.—

While these Italian naturalists, together with Cortesi and Spallanzani, were busily engaged in pointing out the analogy between the deposits of modern and ancient seas, and the habits and arrangement of their organic inhabitants, and while some progress was making, in the same country, in investigating the ancient and modern volcanic rocks, some of the most original observers among the English and German writers, Wallerius and Whitehurst*, were wasting their strength in contending, according to the old Woodwardian hypothesis, that all the strata were formed by the Noachian deluge. But Whitehurst's description of the rocks of Derbyshire was most faithful; and he atoned for false theoretical views, by providing data for their refutation.

Pallas — Saussure. — Towards the close of the eighteenth century, the idea of distinguishing the mineral masses on our globe into separate groups, and studying their relations, began to be generally diffused. Pallas and Saussure were among the most celebrated whose labours contributed to this end. After an attentive examination of the two great mountain chains of Siberia, Pallas announced the result, that the granitic rocks were in the middle, the schistose at their sides, and the limestones again on the outside of these;

tinguished hydrographer, Captain Smyth, on the water within eight fathoms of the surface, that the temperature of the Mediterranean is on an average $3\frac{1}{2}^{\circ}$ of Fahrenheit higher than the western part of the Atlantic ocean; an important fact, which in some degree may help to explain why many species are common to tropical latitudes and to the Mediterranean.

* Inquiry into the Original State and Formation of the Earth. 1778.

and this he conceived would prove a general law in the formation of all chains composed chiefly of primary rocks. *

In his "Travels in Russia," in 1793 and 1794, he made many geological observations on the recent strata near the Wolga and the Caspian, and adduced proofs of the greater extent of the latter sea at no distant era in the earth's history. His memoir on the fossil bones of Siberia attracted attention to some of the most remarkable phenomena in geology. He stated that he had found a rhinoceros entire in the frozen soil, with its skin and flesh: an elephant, found afterwards in a mass of ice on the shore of the North sea, removed all doubt as to the accuracy of so wonderful a discovery. †

The subjects relating to natural history which engaged the attention of Pallas were too multifarious to admit of his devoting a large share of his labours exclusively to geology. Saussure, on the other hand, employed the chief portion of his time in studying the structure of the Alps and Jura, and he provided valuable data for those who followed him. He did not pretend to deduce any general system from his numerous and interesting observations; and the few theoretical opinions which escaped from him, seem, like those of Pallas, to have been chiefly derived from the cosmological speculations of preceding writers.

* *Observ. on the Formation of Mountains.* Act. Petrop. ann. 1778, part i.

† *Nov. comm. Petr. XVII.* Cuvier, *Éloge de Pallas.*

CHAPTER IV.

HISTORY OF THE PROGRESS OF GEOLOGY — *continued.*

Werner's Application of Geology to the Art of Mining — Excursive Character of his Lectures — Enthusiasm of his Pupils — His Authority — His theoretical Errors — Desmarest's Map and Description of Auvergne — Controversy between the Vulcanists and Neptunists — Intemperance of the rival Sects — Hutton's Theory of the Earth — His Discovery of Granite Veins — Originality of his Views — Why opposed — Playfair's Illustrations — Influence of Voltaire's Writings on Geology — Imputations cast on the Huttonians by Williams, Kirwan, and De Luc — Smith's Map of England — Geological Society of London — Progress of the Science in France — Growing Importance of the Study of Organic Remains.

Werner.—THE art of mining has long been taught in France, Germany, and Hungary, in scientific institutions established for that purpose, where mineralogy has always been a principal branch of instruction.*

Werner was named, in 1775, professor of that science in the "School of Mines" at Freyburg, in Saxony. He directed his attention not merely to the composition and external characters of minerals, but also to what he termed "geognosy," or the natural position of

* Our miners have been left to themselves, almost without the assistance of scientific works in the English language, and without any "school of mines," to blunder their own way into a certain degree of practical skill. The inconvenience of this want of system in a country where so much capital is expended, and often wasted, in mining adventures, has been well exposed by an eminent practical miner. — See "Prospectus of a School of Mines in Cornwall, by J. Taylor, 1825."

minerals in particular rocks, together with the grouping of those rocks, their geographical distribution, and various relations. The phenomena observed in the structure of the globe had hitherto served for little else than to furnish interesting topics for philosophical discussion: but when Werner pointed out their application to the practical purposes of mining, they were instantly regarded by a large class of men as an essential part of their professional education, and from that time the science was cultivated in Europe more ardently and systematically. Werner's mind was at once imaginative and richly stored with miscellaneous knowledge. He associated every thing with his favourite science, and in his excursive lectures he pointed out all the economical uses of minerals, and their application to medicine; the influence of the mineral composition of rocks upon the soil, and of the soil upon the resources, wealth, and civilization of man. The vast sandy plains of Tartary and Africa, he would say, retained their inhabitants in the shape of wandering shepherds; the granitic mountains and the low calcareous and alluvial plains gave rise to different manners, degrees of wealth and intelligence. The history even of languages, and the migrations of tribes, had been determined by the direction of particular strata. The qualities of certain stones used in building would lead him to descant on the architecture of different ages and nations; and the physical geography of a country frequently invited him to treat of military tactics. The charm of his manners and his eloquence kindled enthusiasm in the minds of all his pupils; and many, who had only intended at first to acquire a slight knowledge of mineralogy, when they had once heard him, devoted themselves to it as the business of their lives. In a few years, a small

school of mines, before unheard of in Europe, was raised to the rank of a great university; and men already distinguished in science studied the German language, and came from the most distant countries to hear the great oracle of geology. *

Werner had a great antipathy to the mechanical labour of writing, and he could never be persuaded to pen more than a few brief memoirs, and those containing no development of his general views. Although the natural modesty of his disposition was excessive, approaching even to timidity, he indulged in the most bold and sweeping generalizations, and he inspired all his scholars with a most implicit faith in his doctrines. Their admiration of his genius, and the feelings of gratitude and friendship which they all felt for him, were not undeserved; but the supreme authority usurped by him over the opinions of his contemporaries, was eventually prejudicial to the progress of the science; so much so, as greatly to counterbalance the advantages which it derived from his exertions. If it be true that delivery be the first, second, and third requisite in a popular orator, it is no less certain that to travel is of threefold importance to those who desire to originate just and comprehensive views concerning the structure of our globe, and Werner had not travelled to distant countries. He had merely explored a small portion of Germany, and conceived, and persuaded others to believe, that the whole surface of our planet, and all the mountain chains in the world, were made after the model of his own province. It was a ruling object of ambition in the minds of his pupils to confirm the generalizations of their great master, and to discover

* Cuvier, Éloge de Werner.

in the most distant parts of the globe his “universal formations,” which he supposed had been each in succession simultaneously precipitated over the whole earth from a common menstruum, or “chaotic fluid.” It now appears that the Saxon professor had misinterpreted many of the most important appearances in the immediate neighbourhood of Freyberg. Thus, for example, within a day’s journey of his school, the porphyry, called by him primitive, has been found not only to send forth veins or dykes through strata of the coal formation, but to overlie them in mass. The granite of the Hartz mountains, on the other hand, which he supposed to be the nucleus of the chain, is now well known to traverse and breach the other beds, penetrating even into the plain (as near Goslar); and nearer Freyberg, in the Erzgebirge, the mica slate does not mantle round the granite, as was supposed, but abuts abruptly against it. Fragments, also, of the greywacke slate, containing organic remains, have recently been found entangled in the granite of the Hartz, by M. de Seckendorf.*

The principal merit of Werner’s system of instruction consisted in steadily directing the attention of his scholars to the constant relations of superposition of certain mineral groups; but he had been anticipated, as has been shown in the last chapter, in the discovery of this general law, by several geologists in Italy and elsewhere; and his leading divisions of the secondary strata were, at the same time, made the basis of an arrangement of the British strata by our countryman,

* I am indebted for this information partly to Messrs. Sedgwick and Murchison, who have investigated the country, and partly to Dr. Hartmann of Blankenburg, the translator of this work into German.

William Smith, to whose work I shall return by-and-by.

Controversy between the Vulcanists and Neptunists.
—In regard to basalt and other igneous rocks, Werner's theory was original, but it was also extremely erroneous. The basalts of Saxony and Hesse, to which his observations were chiefly confined, consisted of tabular masses capping the hills, and not connected with the levels of existing valleys, like many in Auvergne and the Vivarais. These basalts, and all other rocks of the same family in other countries, were, according to him, chemical precipitates from water. He denied that they were the products of submarine volcanos; and even taught that, in the primeval ages of the world, there were no volcanos. His theory was opposed, in a twofold sense, to the doctrine of the permanent agency of the same causes in nature; for not only did he introduce, without scruple, many imaginary causes supposed to have once effected great revolutions in the earth, and then to have become extinct, but new ones also were feigned to have come into play in modern times; and, above all, that most violent instrument of change, the agency of subterranean fire.

So early as 1768, before Werner had commenced his mineralogical studies, Raspe had truly characterized the basalts of Hesse as of igneous origin. Arduino, as we have already seen, had pointed out numerous varieties of trap-rock in the Vicentin as analogous to volcanic products, and as distinctly referrible to ancient submarine eruptions. Desmarest, as before stated, had, in company with Fortis, examined the Vicentin in 1766, and confirmed Arduino's views. In 1772, Banks, Solander, and Troil compared the columnar basalt of Hecla with that of the Hebrides.

Collini, in 1774, recognized the true nature of the igneous rocks on the Rhine, between Andernach and Bonn. In 1775, Guettard visited the Vivarais, and established the relation of basaltic currents to lavas. Lastly, in 1779, Faujas published his description of the volcanos of the Vivarais and Velay, and showed how the streams of basalt had poured out from craters which still remain in a perfect state.*

Desmarest.—When sound opinions had thus for twenty years prevailed in Europe concerning the true nature of the ancient trap-rocks, Werner by his dictum caused a retrograde movement, and not only overturned the true theory, but substituted for it one of the most unphilosophical that can well be imagined. The continued ascendancy of his dogmas on this subject was the more astonishing, because a variety of new and striking facts were daily accumulated in favour of the correct opinions previously entertained. Desmarest, after a careful examination of Auvergne, pointed out, first, the most recent volcanos which had their craters still entire, and their streams of lava conforming to the level of the present river-courses. He then showed that there were others of an intermediate epoch, whose craters were nearly effaced, and whose lavas were less intimately connected with the present valleys; and, lastly, that there were volcanic rocks still more ancient, without any discernible craters or scorïæ, and bearing the closest analogy to rocks in other parts of Europe, the igneous origin of which was denied by the school of Freyberg.†

* Cuvier, Éloge de Desmarest.

† Journ. de Phys. vol. xiii. p. 115.; and Mém. de l'Inst. Sciences, Mathémat. et Phys. vol. vi. p. 219.

Desmarest's map of Auvergne was a work of uncommon merit. He first made a trigonometrical survey of the district, and delineated its physical geography with minute accuracy and admirable graphic power. He contrived, at the same time, to express, without the aid of colours, a vast quantity of geological detail, the different ages, and sometimes even the structure, of the volcanic rocks, distinguishing them from the fresh-water and the granitic. They alone who have carefully studied Auvergne, and traced the different lava-streams from their craters to their termination, — the various isolated basaltic cappings, — the relation of some lavas to the present valleys, — the absence of such relations in others, — can appreciate the extraordinary fidelity of this elaborate work. No other district of equal dimensions in Europe exhibits, perhaps, so beautiful and varied a series of phenomena; and, fortunately, Desmarest possessed at once the mathematical knowledge required for the construction of a map, skill in mineralogy, and a power of original generalization.

Dolomieu — Montlosier. — Dolomieu, another of Werner's contemporaries, had found prismatic basalt among the ancient lavas of Etna; and, in 1784, had observed the alternations of submarine and calcareous strata in the Val di Noto, in Sicily.* In 1790, he also described similar phenomena in the Vicentin and in the Tyrol.† Montlosier also published, in 1788, an elegant and spirited essay on the volcanos of Auvergne, combining accurate local observations with comprehensive views. Notwithstanding this mass of evidence, the scholars of

* Journ. de Phys. tom. xxv. p. 191.

† Ib. tom. xxxvii. part ii. p. 200.

Werner were prepared to support his opinions to their utmost extent; maintaining, in the fulness of their faith, that even obsidian was an aqueous precipitate. As they were blinded by their veneration for the great teacher, they were impatient of opposition, and soon imbibed the spirit of a faction; and their opponents, the Vulcanists, were not long in becoming contaminated with the same intemperate zeal. Ridicule and irony were weapons more frequently employed than argument by the rival sects, till at last the controversy was carried on with a degree of bitterness almost unprecedented in questions of physical science. Desmarest alone, who had long before provided ample materials for refuting such a theory, kept aloof from the strife; and whenever a zealous Neptunist wished to draw the old man into an argument, he was satisfied with replying, "Go and see." *

Hutton, 1788.—It would be contrary to all analogy, in matters of graver import, that a war should rage with such fury on the Continent, and that the inhabitants of our island should not mingle in the affray. Although in England the personal influence of Werner was wanting to stimulate men to the defence of the weaker side of the question, they contrived to find good reason for espousing the Wernerian errors with great enthusiasm. In order to explain the peculiar motives which led many to enter, even with party feeling, into this contest, it will be necessary to present the reader with a sketch of the views unfolded by Hutton, a contemporary of the Saxon geologist. That naturalist had been educated as a physician, but, declining the practice of medicine, he resolved, when

* Cuvier, *Éloge de Desmarest*.

young, to remain content with the small independence inherited from his father, and thenceforth to give his undivided attention to scientific pursuits. He resided at Edinburgh, where he enjoyed the society of many men of high attainments, who loved him for the simplicity of his manners and the sincerity of his character. His application was unwearied; and he made frequent tours through different parts of England and Scotland, acquiring considerable skill as a mineralogist, and constantly arriving at grand and comprehensive views in geology. He communicated the results of his observations unreservedly, and with the fearless spirit of one who was conscious that love of truth was the sole stimulus of his exertions. When at length he had matured his views, he published, in 1788, his "Theory of the Earth*," and the same, afterwards more fully developed in a separate work, in 1795. This treatise was the first in which geology was declared to be in no way concerned about "questions as to the origin of things;" the first in which an attempt was made to dispense entirely with all hypothetical causes, and to explain the former changes of the earth's crust by reference exclusively to natural agents. Hutton laboured to give fixed principles to geology, as Newton had succeeded in doing to astronomy; but, in the former science, too little progress had been made towards furnishing the necessary data, to enable any philosopher, however great his genius, to realize so noble a project.

Huttonian theory.—“The ruins of an older world,” said Hutton, “are visible in the present structure of our planet; and the strata which now compose our

* Ed. Phil. Trans. 1788.

continents have been once beneath the sea, and were formed out of the waste of pre-existing continents. The same forces are still destroying, by chemical decomposition or mechanical violence, even the hardest rocks, and transporting the materials to the sea, where they are spread out, and form strata analogous to those of more ancient date. Although loosely deposited along the bottom of the ocean, they become afterwards altered and consolidated by volcanic heat, and then heaved up, fractured and contorted."

Although Hutton had never explored any region of active volcanos, he had convinced himself that basalt and many other trap-rocks were of igneous origin, and that many of them had been injected in a melted state through fissures in the older strata. The compactness of these rocks, and their different aspect from that of ordinary lava, he attributed to their having cooled down under the pressure of the sea; and in order to remove the objections started against this theory, his friend, Sir James Hall, instituted a most curious and instructive series of chemical experiments, illustrating the crystalline arrangement and texture assumed by melted matter cooled under high pressure.

The absence of stratification in granite, and its analogy in mineral character to rocks which he deemed of igneous origin, led Hutton to conclude that granite also must have been formed from matter in fusion; and this inference he felt could not be fully confirmed, unless he discovered at the contact of granite and other strata a repetition of the phenomena exhibited so constantly by the trap-rocks. Resolved to try his theory by this test, he went to the Grampians, and surveyed the line of junction of the granite and super-incumbent stratified masses, until he found in Glen Tilt,

in 1785, the most clear and unequivocal proofs in support of his views. Veins of red granite are there seen branching out from the principal mass, and traversing the black micaceous schist and primary limestone. The intersected stratified rocks are so distinct in colour and appearance as to render the example in that locality most striking, and the alteration of the limestone in contact was very analogous to that produced by trap veins on calcareous strata. This verification of his system filled him with delight, and called forth such marks of joy and exultation, that the guides who accompanied him, says his biographer, were convinced that he must have discovered a vein of silver or gold.* He was aware that the same theory would not explain the origin of the primary schists, but these he called primary, rejecting the term primitive, and was disposed to consider them as sedimentary rocks altered by heat, and that they originated in some other form from the waste of previously existing rocks.

By this important discovery of granite veins, to which he had been led by fair induction from an independent class of facts, Hutton prepared the way for the greatest innovation on the systems of his predecessors. Vallisneri had pointed out the general fact that there were certain fundamental rocks which contained no organic remains, and which he supposed to have been formed before the creation of living beings. Moro, Generelli, and other Italian writers, embraced the same doctrine; and Lehman regarded the mountains called by him primitive, as parts of the original nucleus of the globe. The same tenet was an article

* Playfair's Works, vol. iv. p. 75.

of faith in the school of Freyberg; and if any one ventured to doubt the possibility of our being enabled to carry back our researches to the creation of the present order of things, the granitic rocks were triumphantly appealed to. On them seemed written, in legible characters, the memorable inscription —

Dinanzi a me non fur cose create

Se non eterne;

and no small sensation was excited when Hutton seemed, with unhallowed hand, desirous to erase characters already regarded by many as sacred. “In the economy of the world,” said the Scotch geologist, “I can find no traces of a beginning, no prospect of an end;” a declaration the more startling when coupled with the doctrine, that all past changes on the globe had been brought about by the slow agency of existing causes. The imagination was first fatigued and overpowered by endeavouring to conceive the immensity of time required for the annihilation of whole continents by so insensible a process; and when the thoughts had wandered through these interminable periods, no resting place was assigned in the remotest distance. The oldest rocks were represented to be of a derivative nature, the last of an antecedent series, and that perhaps one of many pre-existing worlds. Such views of the immensity of past time, like those unfolded by the Newtonian philosophy in regard to space, were too vast to awaken ideas of sublimity unmixed with a painful sense of our incapacity to conceive a plan of such infinite extent. Worlds are seen beyond worlds immeasurably distant from each other, and, beyond them all, innumerable other systems are faintly traced on the confines of the visible universe.

The characteristic feature of the Huttonian theory

was, as before hinted, the exclusion of all causes not supposed to belong to the present order of nature. Its greatest defect consisted in the undue influence attributed to subterranean heat, which was supposed necessary for the consolidation of all submarine deposits. Hutton made no step beyond Hooke, Moro, and Raspe, in pointing out in what manner the laws now governing earthquakes might bring about geological changes, if sufficient time be allowed. On the contrary, he seems to have fallen far short of some of their views. He imagined that the continents were first gradually destroyed; and that when their ruins had furnished materials for new continents, they were upheaved by violent and paroxysmal convulsions. He therefore required alternate periods of general disturbance and repose; and such he believed had been, and would for ever be, the course of nature.

Generelli, in his exposition of Moro's system, had made a far nearer approximation towards reconciling geological appearances with the state of nature as known to us; for while he agreed with Hutton, that the decay and reproduction of rocks were always in progress, proceeding with the utmost uniformity, the learned Carmelite represented the repairs of mountains by elevation from below to be effected by an equally constant and synchronous operation. Neither of these theories, considered singly, satisfies all the conditions of the great problem, which a geologist, who rejects cosmological causes, is called upon to solve; but they probably contain together the germs of a perfect system. There can be no doubt, that periods of disturbance and repose have followed each other in succession in every region of the globe; but it may be equally true, that the energy of the subter-

ranee movements has been always uniform as regards the *whole earth*. The force of earthquakes may for a cycle of years have been invariably confined, as it is now, to large but determinate spaces, and may then have gradually shifted its position, so that another region, which had for ages been at rest, became in its turn the grand theatre of action.

Playfair's illustrations of Hutton. — Although Hutton's knowledge of mineralogy and chemistry was considerable, he possessed but little information concerning organic remains. They merely served him, as they did Werner, to characterize certain strata, and to prove their marine origin. The theory of former revolutions in organic life was not yet fully recognized; and without this class of proofs in support of the antiquity of the globe, the indefinite periods demanded by the Huttonian hypothesis appeared visionary to many; and some, who deemed the doctrine inconsistent with revealed truths, indulged very uncharitable suspicions of the motives of its author. They accused him of a deliberate design of reviving the heathen dogma of an "eternal succession," and of denying that this world ever had a beginning. Playfair, in the biography of his friend, has the following comment on this part of their theory: — "In the planetary motions, where geometry has carried the eye so far, both into the future and the past, we discover no mark either of the commencement or termination of the present order. It is unreasonable, indeed, to suppose that such marks should any where exist. The Author of Nature has not given laws to the universe, which, like the institutions of men, carry in themselves the elements of their own destruction. He has not permitted in His works any symptom of infancy or of old age, or any sign by

which we may estimate either their future or their past duration. *He may put an end, as he no doubt gave a beginning,* to the present system, at some determinate period of time; but we may rest assured that this great catastrophe will not be brought about by the laws now existing, and that it is not indicated by any thing which we perceive." *

The party feeling excited against the Huttonian doctrines, and the open disregard of candour and temper in the controversy, will hardly be credited by the reader, unless he recalls to his recollection that the mind of the English public was at that time in a state of feverish excitement. A class of writers in France had been labouring industriously, for many years, to diminish the influence of the clergy, by sapping the foundations of the Christian faith; and their success, and the consequences of the Revolution, had alarmed the most resolute minds, while the imagination of the more timid was continually haunted by dread of innovation, as by the phantom of some fearful dream.

Voltaire.—Voltaire had used the modern discoveries in physics as one of the numerous weapons of attack and ridicule directed by him against the Scriptures. He found that the most popular systems of geology were accommodated to the sacred writings, and that much ingenuity had been employed to make every fact coincide exactly with the Mosaic account of the creation and deluge. It was, therefore, with no friendly feelings that he contemplated the cultivators of geology in general, regarding the science as one which had been successfully enlisted by theologians as

* Playfair's Works, vol. iv. p. 55.

an ally in their cause.* He knew that the majority of those who were aware of the abundance of fossil shells in the interior of continents, were still persuaded that they were proofs of the universal deluge; and as the readiest way of shaking this article of faith, he endeavoured to inculcate scepticism as to the real nature of such shells, and to recall from contempt the exploded dogma of the sixteenth century, that they were sports of nature. He also pretended that vegetable impressions were not those of real plants.† Yet he was perfectly convinced that the shells had really belonged to living testacea, as may be seen in his essay “On the Formation of Mountains.”‡ He would sometimes, in defiance of all consistency, shift his ground when addressing the vulgar; and, admitting the true nature of the shells collected in the Alps and other places, pretend that they were Eastern species, which had fallen from the hats of pilgrims coming from Syria. The numerous essays written by

* In allusion to the theories of Burnet, Woodward, and other physico-theological writers, he declared that they were as fond of changes of scene on the face of the globe, as were the populace at a play. “Every one of them destroys and renovates the earth after his own fashion, as Descartes framed it: for philosophers put themselves without ceremony in the place of God, and think to create a universe with a word.” — *Dissertation envoyée à l’Académie de Boulogne, sur les Changemens arrivés dans notre Globe.* Unfortunately, this and similar ridicule directed against the cosmogonists was too well deserved.

† See the chapter on “Des Pierres figurées.”

‡ In that essay he lays it down, “that all naturalists are now agreed that deposits of shells in the midst of the continents are monuments of the continued occupation of these districts by the ocean.” In another place also, when speaking of the fossil shells of Touraine, he admits their true origin.

him on geological subjects were all calculated to strengthen prejudices, partly because he was ignorant of the real state of the science, and partly from his bad faith.* On the other hand, they who knew that his attacks were directed by a desire to invalidate Scripture, and who were unacquainted with the true merits of the question, might well deem the old diluvian hypothesis incontrovertible, if Voltaire could adduce no better argument against it than to deny the true nature of organic remains.

It is only by careful attention to impediments originating in extrinsic causes, that we can explain the slow and reluctant adoption of the simplest truths in geology. First, we find many able naturalists adducing the fossil remains of marine animals as proofs of an event related in Scripture. The evidence is deemed conclusive by the multitude for a century or more ; for it favours opinions which they entertained before, and they are gratified by supposing them confirmed by fresh and unexpected proofs. Many, who see through the fallacy, have no wish to undeceive those who are influenced by it, approving the effect of the delusion, and conniving at it as a pious fraud ; until, finally, an opposite party, who are hostile to the sacred writings, labour to explode the erroneous opinion, by substituting for it another dogma which they know to be equally unsound.

The heretical Vulcanists were now openly assailed

* As an instance of his desire to throw doubt indiscriminately on all geological data, we may recall the passage where he says, that " the bones of a rein-deer and hippopotamus discovered near Etampes did not prove, as some would have it, that Lapland and the Nile were once on a tour from Paris to Orleans, but merely that a lover of curiosities once preserved them in his cabinet."

in England, by imputations of the most illiberal kind. We cannot estimate the malevolence of such a persecution, by the pain which similar insinuations might now inflict; for although charges of infidelity and atheism must always be odious, they were injurious in the extreme at that moment of political excitement: and it was better perhaps, for a man's good reception in society, that his moral character should have been traduced, than that he should become a mark for these poisoned weapons.

I shall pass over the works of numerous divines, who may be excused for sensitiveness on points which then excited so much uneasiness in the public mind; and shall say nothing of the amiable poet Cowper*, who could hardly be expected to have inquired into the merit of doctrines in physics. But in the foremost ranks of the intolerant, are found several laymen who had high claims to scientific reputation. Among these appears Williams, a mineral surveyor of Edinburgh, who published a "Natural History of the Mineral Kingdom," in 1789; a work of great merit for that day, and of practical utility, as containing the best account of the coal strata. In his preface he misrepresents Hutton's theory altogether, and charges him with considering all rocks to be lavas of different colours and structure; and also with "warping every thing to support the eternity of the world."† He descants on the pernicious influence of such sceptical notions, as leading to downright infidelity and atheism, "and as being nothing less than to depose the Almighty Creator of the universe from his office."‡

* The Task, book iii. "The Garden."

† P. 577.

‡ P. 59.

Kirwan, 1799.—Kirwan, president of the Royal Academy of Dublin, a chemist and mineralogist of some merit, but who possessed much greater authority in the scientific world than he was entitled by his talents to enjoy, said, in the introduction to his “Geological Essays, 1799,” “that *sound* geology *graduated* into religion, and was required to dispel certain systems of atheism or infidelity, of which they had had recent experience.”* He was an uncompromising defender of the aqueous theory of all rocks, and was scarcely surpassed by Burnet and Whiston, in his desire to adduce the Mosaic writings in confirmation of his opinions.

De Luc.—De Luc, in the preliminary discourse to his *Treatise on Geology*†, says, “the weapons have been changed by which revealed religion is attacked; it is now assailed by geology, and the knowledge of this science has become essential to theologians.” He imputes the failure of former geological systems to their having been anti-mosaical, and directed against a “sublime tradition.” These and similar imputations, reiterated in the works of De Luc, seem to have been taken for granted by some modern writers: it is therefore necessary to state, in justice to the numerous geologists of different nations, whose works have been considered, that none of them were guilty of endeavouring, by arguments drawn from physics, to invalidate scriptural tenets. On the contrary, the majority of them, who were fortunate enough “to discover the true causes of things,” rarely deserved another part of the poet’s panegyric, “*Atque metus omnes subjecit pedibus*.” The caution, and even timid reserve, of

* *Intro.* p. 2.

† London, 1809.

many eminent Italian authors of the earlier period is very apparent; and there can hardly be a doubt that they subscribed to certain dogmas, and particularly to the first diluvian theory, out of deference to popular prejudices, rather than from conviction. But if they were guilty of dissimulation, we must not blame their want of moral courage, reserving rather our condemnation for the intolerance of the times, and that inquisitorial power which forced Galileo to abjure, and the two Jesuits to disclaim the theory of Newton.*

Hutton answered Kirwan's attacks with great warmth, and with the indignation excited by unmerited reproach. He had always displayed, says Playfair, "the utmost disposition to admire the beneficent design manifested in the structure of the world; and he contemplated with delight those parts of his theory which made the greatest additions to our knowledge of final causes." We may say with equal truth, that in no scientific

* In a most able and interesting article, the "Life of Galileo," recently published in the "Library of Useful Knowledge," it is asserted that both Galileo's work, and the book of Copernicus "Nisi corrigatur," were still to be seen on the forbidden list of the Index at Rome in 1828. But I was assured in the same year, by Professor Scarpellini, at Rome, that Pius VII., a pontiff distinguished for his love of science, procured, in 1818, a repeal of the edicts against Galileo and the Copernican system. He assembled the Congregation; and the late Cardinal Toriozzi, assessor of the Sacred Office, proposed "that they should wipe off this scandal from the church." The repeal was carried, with the dissentient voice of one Dominican only. Long before this time the Newtonian theory had been taught in the Sapienza, and all Catholic universities in Europe (with the exception, I am told, of Salamanca); but it was always required of professors, in deference to the decrees of the church, to use the term *hypothesis*, instead of theory. They now speak of the Copernican *theory*.

works in our language can more eloquent passages be found, concerning the fitness, harmony, and grandeur of all parts of the creation, than in those of Playfair. They are evidently the unaffected expressions of a mind, which contemplated the study of nature, as best calculated to elevate our conceptions of the attributes of the First Cause. At any other time the force and elegance of Playfair's style must have insured popularity to the Huttonian doctrines; but, by a singular coincidence, Neptunianism and orthodoxy were now associated in the same creed; and the tide of prejudice ran so strong, that the majority were carried far away into the chaotic fluid, and other cosmological inventions of Werner. These fictions the Saxon professor had borrowed with little modification, and without any improvement, from his predecessors. They had not the smallest foundation either in Scripture or in common sense, but were perhaps approved of by many as being so ideal and unsubstantial, that they could never come into violent collision with any preconceived opinions.

According to De Luc, the first essential distinction to be made between the various phenomena exhibited on the surface of the earth was, to determine which were the results of causes still in action, and which had been produced by causes that had ceased to act. The form and composition of the mass of our continents, he said, and their existence above the level of the sea, must be ascribed to causes no longer in action. These continents emerged at no very remote period on the sudden retreat of the ocean, the waters of which made their way into subterranean caverns. The formation of the rocks which enter into the crust of the earth began with the precipitation of granite from a primordial liquid, after which other strata

containing the remains of organized bodies were deposited, till at last the present sea remained as the residuum of the primordial liquid, and no longer continued to produce mineral strata.*

William Smith, 1790.—While the tenets of the rival schools of Freyberg and Edinburgh were warmly espoused by devoted partisans, the labours of an individual, unassisted by the advantages of wealth or station in society, were almost unheeded. Mr. William Smith, an English surveyor, published his “*Tabular View of the British Strata*” in 1790, wherein he proposed a classification of the secondary formations in the West of England. Although he had not communicated with Werner, it appeared by this work that he had arrived at the same views respecting the laws of superposition of stratified rocks; that he was aware that the order of succession of different groups was never inverted; and that they might be identified at very distant points by their peculiar organized fossils.

From the time of the appearance of the “*Tabular View*,” he laboured to construct a geological map of the whole of England; and, with the greatest disinterestedness of mind, communicated the results of his investigations to all who desired information, giving such publicity to his original views, as to enable his contemporaries almost to compete with him in the race. The execution of his map was completed in 1815, and remains a lasting monument of original talent and extraordinary perseverance; for he had explored the whole country on foot without the guidance of previous observers, or the aid of fellow labourers, and had

* *Elementary Treatise on Geology*. London, 1809. Translated by De la Fite.

succeeded in throwing into natural divisions the whole complicated series of British rocks.* D'Aubuisson, a distinguished pupil of Werner, paid a just tribute of praise to this remarkable performance, observing, that "what many celebrated mineralogists had only accomplished for a small part of Germany in the course of half a century, had been effected by a single individual for the whole of England."†

MODERN PROGRESS OF GEOLOGY.

Having now arrived at the era of living authors, I shall bring to a conclusion this sketch of the progress of opinion in geology. The contention of the rival factions of the Vulcanists and Neptunists had been carried to such a height, that these names had become terms of reproach; and the two parties had been less occupied in searching for truth, than for such arguments as might strengthen their own cause, or serve to annoy their antagonists. A new school at last arose, who professed the strictest neutrality, and the utmost indifference to the systems of Werner and Hutton, and who resolved diligently to devote their labours to observation. The reaction, provoked by the intemperance of the conflicting parties, now produced a tendency to extreme caution. Speculative views were discounte-

* Werner invented a new language to express his divisions of rocks, and some of his technical terms, such as *grauwacke*, *gneiss*, and others, passed current in every country in Europe. Smith adopted for the most part English provincial terms, often of barbarous sound, such as *gault*, *cornbrash*, *clunch clay*, &c., and affixed them to subdivisions of the British series. Many of these still retain their place in our scientific classifications, and attest his priority of arrangement.

† See Dr. Fitton's *Memoir*, before cited, p. 57.

nanced, and, through fear of exposing themselves to the suspicion of a bias towards the dogmas of a party, some geologists became anxious to entertain no opinion whatever on the causes of phenomena, and were inclined to scepticism even where the conclusions deducible from observed facts scarcely admitted of reasonable doubt.

Geological Society of London.—But although the reluctance to theorize was carried somewhat to excess, no measure could be more salutary at such a moment than a suspension of all attempts to form what were termed “theories of the earth.” A great body of new data were required; and the Geological Society of London, founded in 1807, conduced greatly to the attainment of this desirable end. To multiply and record observations, and patiently to await the result at some future period, was the object proposed by them; and it was their favourite maxim that the time was not yet come for a general system of geology, but that all must be content for many years to be exclusively engaged in furnishing materials for future generalizations. By acting up to these principles with consistency, they in a few years disarmed all prejudice, and rescued the science from the imputation of being a dangerous, or at best but a visionary pursuit.

A distinguished modern writer * has with truth remarked, that the advancement of three of the main divisions of geological inquiry have, during the last half century, been promoted successively by three different nations of Europe,—the Germans, the English, and the French. We have seen that the systematic study of what may be called mineralogical geology had

* Whewell, *British Critic*, No. xvii. p. 187. 1831.

its origin, and chief point of activity, in Germany, where Werner first described with precision the mineral characters of rocks. The classification of the secondary formations, each marked by their peculiar fossils, belongs, in a great measure, to England, where the labours before alluded to of Smith, and those of the most active members of the Geological Society of London, were steadily directed to these objects. The foundation of the third branch, that relating to the tertiary formations, was laid in France by the splendid work of Cuvier and Brongniart, published in 1808, "On the Mineral Geography and Organic Remains of the Neighbourhood of Paris."

We may still trace, in the language of the science and our present methods of arrangement, the various countries where the growth of these several departments of geology was at different times promoted. Many names of simple minerals and rocks remain to this day German, while the European divisions of the secondary strata are in great part English, and are, indeed, often founded too exclusively on English types. Lastly, the subdivisions first established of the succession of strata in the Paris basin have served as normal groups, to which other tertiary deposits throughout Europe have been compared, even in cases where this standard, as the reader will afterwards learn, was wholly inapplicable.*

No period could have been more fortunate for the discovery, in the immediate neighbourhood of Paris, of a rich store of well-preserved fossils, than the commencement of the present century; for at no former era had Natural History been cultivated with such

* Book iv. chap. ii.

enthusiasm in the French metropolis : the labours of Cuvier in comparative osteology, and of Lamarck in recent and fossil shells, having raised these departments of study to a rank of which they had never previously been deemed susceptible. Their investigations had eventually a powerful effect in dispelling the illusion which had long prevailed concerning the absence of analogy between the ancient and modern state of our planet. A close comparison of the recent and fossil species, and the inferences drawn in regard to their habits, accustomed the geologist to contemplate the earth as having been at successive periods the dwelling-place of animals and plants of different races, some of which were discovered to have been terrestrial, and others aquatic—some fitted to live in seas, others in the waters of lakes and rivers. By the consideration of these topics, the mind was slowly and insensibly withdrawn from imaginary pictures of catastrophes and chaotic confusion, such as haunted the imagination of the early cosmogonists. Numerous proofs were discovered of the tranquil deposition of sedimentary matter, and the slow development of organic life. If many writers, and Cuvier himself in the number, still continued to maintain, that “the thread of induction was broken,” yet, in reasoning by the strict rules of induction from recent to fossil species, they in a great measure disclaimed the dogma which in theory they professed. The adoption of the same generic, and, in some cases, even the same specific, names for the exuviae of fossil animals, and their living analogues, was an important step towards familiarizing the mind with the idea of the identity and unity of the system in distant eras. It was an acknowledgment, as it were, that part at least of the ancient memorials of nature were written in a

living language. The growing importance, then, of the natural history of organic remains may be pointed out as the characteristic feature of the progress of the science during the present century. This branch of knowledge has already become an instrument of great utility in geological classification, and is continuing daily to unfold new data for grand and enlarged views respecting the former changes of the earth.

When we compare the result of observations in the last thirty years with those of the three preceding centuries, we cannot but look forward with the most sanguine expectations to the degree of excellence to which geology may be carried, even by the labours of the present generation. Never, perhaps, did any science, with the exception of astronomy, unfold, in an equally brief period, so many novel and unexpected truths, and overturn so many preconceived opinions. The senses had for ages declared the earth to be at rest, until the astronomer taught that it was carried through space with inconceivable rapidity. In like manner was the surface of this planet regarded as having remained unaltered since its creation, until the geologist proved that it had been the theatre of reiterated change, and was still the subject of slow but never-ending fluctuations. The discovery of other systems in the boundless regions of space was the triumph of astronomy: to trace the same system through various transformations—to behold it at successive eras adorned with different hills and valleys, lakes and seas, and peopled with new inhabitants, was the delightful meed of geological research. By the geometer were measured the regions of space, and the relative distances of the heavenly bodies—by the geologist myriads of ages were reckoned, not by arithmetical computation, but by

a train of physical events—a succession of phenomena in the animate and inanimate worlds—signs which convey to our minds more definite ideas than figures can do of the immensity of time.

Whether our investigation of the earth's history and structure will eventually be productive of as great practical benefits to mankind, as a knowledge of the distant heavens, must remain for the decision of posterity. It was not till astronomy had been enriched by the observations of many centuries, and had made its way against popular prejudices to the establishment of a sound theory, that its application to the useful arts was most conspicuous. The cultivation of geology began at a later period; and in every step which it has hitherto made towards sound theoretical principles, it has had to contend against more violent prepossessions. The practical advantages already derived from it have not been inconsiderable: but our generalizations are yet imperfect, and they who follow may be expected to reap the most valuable fruits of our labour. Meanwhile the charm of first discovery is our own; and as we explore this magnificent field of inquiry, the sentiment of a great historian of our times may continually be present to our minds, that "he who calls what has vanished back again into being, enjoys a bliss like that of creating." *

* Niebuhr's *Hist. of Rome*, vol. i. p. 5. Hare and Thirlwall's translation.

CHAPTER V.

CAUSES WHICH HAVE RETARDED THE PROGRESS OF GEOLOGY.

Effects of prepossessions in regard to the duration of past time —

Of prejudices arising from our peculiar position as inhabitants of the land — Of those occasioned by our not seeing subterranean changes now in progress — All these causes combine to make the former course of Nature appear different from the present. — Several objections to the assumption, that existing causes have produced the former changes of the earth's surface, removed by modern discoveries.

IF we reflect on the history of the progress of geology, as explained in the preceding chapters, we perceive that there have been great fluctuations of opinion respecting the nature of the causes to which all former changes of the earth's surface are referrible. The first observers conceived the monuments which the geologist endeavours to decipher to relate to an original state of the earth, or to a period when there were causes in activity, distinct, in kind and degree, from those now constituting the economy of nature. These views were gradually modified, and some of them entirely abandoned in proportion as observations were multiplied, and the signs of former mutations more skilfully interpreted. Many appearances, which had for a long time been regarded as indicating mysterious and extraordinary agency, were finally recognized as the necessary result of the laws now

governing the material world; and the discovery of this unlooked for conformity has at length induced some philosophers to infer, that, during the ages contemplated in geology, there has never been any interruption to the agency of the same uniform laws of change. The same assemblage of general causes, they conceive, may have been sufficient to produce, by their various combinations, the endless diversity of effects, of which the shell of the earth has preserved the memorials; and, consistently with these principles, the recurrence of analogous changes is expected by them in time to come.

Whether we coincide or not in this doctrine, we must admit that the gradual progress of opinion concerning the succession of phenomena in very remote eras, resembles, in a singular manner, that which has accompanied the growing intelligence of every people, in regard to the economy of nature in their own times. In an early stage of advancement, when a great number of natural appearances are unintelligible, an eclipse, an earthquake, a flood, or the approach of a comet, with many other occurrences afterwards found to belong to the regular course of events, are regarded as prodigies. The same delusion prevails as to moral phenomena, and many of these are ascribed to the intervention of demons, ghosts, witches, and other immaterial and supernatural agents. By degrees, many of the enigmas of the moral and physical world are explained, and, instead of being due to extrinsic and irregular causes, they are found to depend on fixed and invariable laws. The philosopher at last becomes convinced of the undeviating uniformity of secondary causes, and, guided by his faith in this principle, he determines the probability of accounts transmitted to

him of former occurrences, and often rejects the fabulous tales of former times, on the ground of their being irreconcilable with the experience of more enlightened ages.

Prepossessions in regard to the duration of past time.—As a belief in the want of conformity in the causes by which the earth's crust has been modified in ancient and modern periods was, for a long time, universally prevalent, and that, too, amongst men who have been convinced that the order of nature is *now* uniform, and that it has continued so for several thousand years, every circumstance which could have influenced their minds and given an undue bias to their opinions deserves particular attention. Now the reader may easily satisfy himself, that, however undeviating the course of nature may have been from the earliest epochs, it was impossible for the first cultivators of geology to come to such a conclusion, so long as they were under a delusion as to the age of the world, and the date of the first creation of animate beings. However fantastical some theories of the sixteenth century may now appear to us,—however unworthy of men of great talent and sound judgment,—we may rest assured that, if the same misconceptions now prevailed in regard to the memorials of human transactions, it would give rise to a similar train of absurdities. Let us imagine, for example, that Champollion, and the French and Tuscan literati lately engaged in exploring the antiquities of Egypt, had visited that country with a firm belief that the banks of the Nile were never peopled by the human race before the beginning of the nineteenth century, and that their faith in this dogma was as difficult to shake as the opinion of our ancestors, that the earth was never the abode of living

beings until the creation of the present continents, and of the species now existing,—it is easy to perceive what extravagant systems they would frame, while under the influence of this delusion, to account for the monuments discovered in Egypt. The sight of the pyramids, obelisks, colossal statues, and ruined temples, would fill them with such astonishment, that for a time they would be as men spell-bound—wholly incapable to reason with sobriety. They might incline at first to refer the construction of such stupendous works to some superhuman powers of a primeval world. A system might be invented resembling that so gravely advanced by Manetho, who relates that a dynasty of gods originally ruled in Egypt, of whom Vulcan, the first monarch, reigned nine thousand years; after whom came Hercules and other demigods, who were at last succeeded by human kings.

When some fanciful speculations of this kind had amused the imagination for a time, some vast repository of mummies would be discovered, and would immediately undeceive those antiquaries who enjoyed an opportunity of personally examining them; but the prejudices of others at a distance, who were not eye-witnesses of the whole phenomena, would not be so easily overcome. The concurrent report of many travellers would indeed render it necessary for them to accommodate ancient theories to some of the new facts, and much wit and ingenuity would be required to modify and defend their old positions. Each new invention would violate a greater number of known analogies; for if a theory be required to embrace some false principle, it becomes more visionary in proportion as facts are multiplied, as would be the case if geometers were now required to form an

astronomical system on the assumption of the immobility of the earth.

Amongst other fanciful conjectures concerning the history of Egypt, we may suppose some of the following to be started. "As the banks of the Nile have been so recently colonized for the first time, the curious substances called mummies could never in reality have belonged to men. They may have been generated by some *plastic virtue* residing in the interior of the earth, or they may be abortions of nature produced by her incipient efforts in the work of creation. For if deformed beings are sometimes born even now, when the scheme of the universe is fully developed, many more may have been 'sent before their time, scarce half made up,' when the planet itself was in the embryo state. But if these notions appear to derogate from the perfection of the Divine attributes, and if these mummies be in all their parts true representations of the human form, may we not refer them to the future rather than the past? May we not be looking into the womb of Nature, and not her grave? May not these images be like the shades of the unborn in Virgil's Elysium—the archetypes of men not yet called into existence?"

These speculations, if advocated by eloquent writers, would not fail to attract many zealous votaries, for they would relieve men from the painful necessity of renouncing preconceived opinions. Incredible as such scepticism may appear, it would be rivalled by many systems of the sixteenth and seventeenth centuries, and among others by that of the learned Falloppio, who regarded the tusks of fossil elephants as earthy concretions, and the pottery or fragments of vases in the Monte Testaceo, near Rome, as works of nature, and

not of art. But when one generation had passed away, and another not compromised to the support of antiquated dogmas had succeeded, they would review the evidence afforded by mummies more impartially, and would no longer controvert the preliminary question, that human beings had lived in Egypt before the nineteenth century: so that when a hundred years perhaps had been lost, the industry and talents of the philosopher would be at last directed to the elucidation of points of real historical importance.

But the above arguments are aimed against one only of many prejudices with which the earlier geologists had to contend. Even when they conceded that the earth had been peopled with animate beings at an earlier period than was at first supposed, they had no conception that the quantity of time bore so great a proportion to the historical era as is now generally conceded. How fatal every error as to the quantity of time must prove to the introduction of rational views concerning the state of things in former ages, may be conceived by supposing the annals of the civil and military transactions of a great nation to be perused under the impression that they occurred in a period of one hundred instead of two thousand years. Such a portion of history would immediately assume the air of a romance; the events would seem devoid of credibility, and inconsistent with the present course of human affairs. A crowd of incidents would follow each other in thick succession. Armies and fleets would appear to be assembled only to be destroyed, and cities built merely to fall in ruins. There would be the most violent transitions from foreign or intestine war to periods of profound peace, and the works effected during the years of disorder or

tranquillity would appear alike superhuman in magnitude.

He who should study the monuments of the natural world under the influence of a similar infatuation, must draw a no less exaggerated picture of the energy and violence of causes, and must experience the same insurmountable difficulty in reconciling the former and present state of nature. If we could behold in one view all the volcanic cones thrown up in Iceland, Italy, Sicily, and other parts of Europe, during the last five thousand years, and could see the lavas which have flowed during the same period ; the dislocations, subsidences, and elevations caused by earthquakes ; the lands added to various deltas, or devoured by the sea, together with the effects of devastation by floods, and imagine that all these events had happened in one year, we must form most exalted ideas of the activity of the agents, and the suddenness of the revolutions. Were an equal amount of change to pass before our eyes in the next year, could we avoid the conclusion that some great crisis of nature was at hand ? If geologists, therefore, have misinterpreted the signs of a succession of events, so as to conclude that centuries were implied where the characters imported thousands of years, and thousands of years where the language of nature signified millions, they could not, if they reasoned logically from such false premises, come to any other conclusion than that the system of the natural world had undergone a complete revolution.

We should be warranted in ascribing the erection of the great pyramid to superhuman power, if we were convinced that it was raised in one day ; and if we imagine, in the same manner, a mountain-chain to have been elevated, during an equally small fraction

of the time which was really occupied in upheaving it, we might then be justified in inferring, that the subterranean movements were once far more energetic than in our own times. We know that one earthquake may raise the coast of Chili for a hundred miles to the average height of about five feet. A repetition of two thousand shocks, of equal violence, might produce a mountain-chain one hundred miles long, and ten thousand feet high. Now, should one only of these convulsions happen in a century, it would be consistent with the order of events experienced by the Chilians from the earliest times ; but if the whole of them were to occur in the next hundred years, the entire district must be depopulated, scarcely any animals or plants could survive, and the surface would be one confused heap of ruin and desolation.

One consequence of undervaluing greatly the quantity of past time, is the apparent coincidence which it occasions of events necessarily disconnected, or which are so unusual, that it would be inconsistent with all calculation of chances to suppose them to happen at one and the same time. When the unlooked-for association of such rare phenomena is witnessed in the present course of nature, it scarcely ever fails to excite a suspicion of the preternatural in those minds which are not firmly convinced of the uniform agency of secondary causes ;—as if the death of some individual in whose fate they are interested happens to be accompanied by the appearance of a luminous meteor, or a comet, or the shock of an earthquake. It would be only necessary to multiply such coincidences indefinitely, and the mind of every philosopher would be disturbed. Now it would be difficult to exaggerate the number of physical events, many of them most

rare and unconnected in their nature, which were imagined by the Woodwardian hypothesis to have happened in the course of a few months: and numerous other examples might be found of popular geological theories, which require us to imagine that a long succession of events happened in a brief and almost momentary period.

• Another liability to error, very nearly allied to the former, arises from the frequent contact of geological monuments referring to very distant periods of time. We often behold, at one glance, the effects of causes which have happened at times incalculably remote, and yet there may be no striking circumstances to mark the occurrence of a great chasm in the chronological series of Nature's archives. In the vast interval of time which may really have elapsed between the results of operations thus compared, the physical condition of the earth may, by slow and insensible modifications, have become entirely altered; one or more races of organic beings may have passed away, and yet have left behind, in the particular region under contemplation, no trace of their existence.

To a mind unconscious of these intermediate events, the passage from one state of things to another must appear so violent, that the idea of revolutions in the system inevitably suggests itself. The imagination is as much perplexed by the deception, as it might be if two distant points in space were suddenly brought into immediate proximity. Let us suppose, for a moment, that a philosopher should lie down to sleep in some arctic wilderness, and then be transferred by a power, such as we read of in tales of enchantment, to a valley in a tropical country, where, on awaking, he might find him-

self surrounded by birds of brilliant plumage, and all the luxuriance of animal and vegetable forms of which Nature is so prodigal in these regions. The most reasonable supposition, perhaps, which he could make, if by the necromancer's art he was placed in such a situation, would be, that he was dreaming; and if a geologist form theories under a similar delusion, we cannot expect him to preserve more consistency in his speculations, than in the train of ideas in an ordinary dream.

The sources of prejudice hitherto considered may be deemed peculiar for the most part to the infancy of the science, but others are common to the first cultivators of geology and to ourselves, and are all singularly calculated to produce the same deception, and to strengthen our belief that the course of nature in the earlier ages differed widely from that now established. Although these circumstances cannot be fully explained without assuming some things as proved, which it will be the object of another part of this work to demonstrate, it may be well to allude to them briefly in this place.

Prejudices arising from our peculiar position as inhabitants of the land.—The first and greatest difficulty, then, consists in our habitual unconsciousness that our position as observers is essentially unfavourable, when we endeavour to estimate the magnitude of the changes now in progress. In consequence of our inattention to this subject, we are liable to the greatest mistakes in contrasting the present with former states of the globe. As dwellers on the land, we inhabit about a fourth part of the surface; and that portion is almost exclusively the theatre of decay, and not of reproduction. We know, indeed, that new deposits are annually formed in seas and

lakes, and that every year some new igneous rocks are produced in the bowels of the earth, but we cannot watch the progress of their formation ; and as they are only present to our minds by the aid of reflection, it requires an effort both of the reason and the imagination to appreciate duly their importance. It is, therefore, not surprising that we imperfectly estimate the result of operations invisible to us ; and that, when analogous results of some former epoch are presented to our inspection, we cannot recognize the analogy. He who has observed the quarrying of stone from a rock, and has seen it shipped for some distant port, and then endeavours to conceive what kind of edifice will be raised by the materials, is in the same predicament as a geologist, who, while he is confined to the land, sees the decomposition of rocks, and the transportation of matter by rivers to the sea, and then endeavours to picture to himself the new strata which Nature is building beneath the waters.

Prejudices arising from our not seeing subterranean changes.—Nor is his position less unfavourable when, beholding a volcanic eruption, he tries to conceive what changes the column of lava has produced, in its passage upwards, on the intersected strata ; or what form the melted matter may assume at great depths on cooling down ; or what may be the extent of the subterranean rivers and reservoirs of liquid matter far beneath the surface. It should, therefore, be remembered, that the task imposed on those who study the earth's history requires no ordinary share of discretion, for we are precluded from collating the corresponding parts of the system of things as it exists at two different periods. If we were inhabitants of another element—if the great ocean were our domain, instead of the narrow limits of

the land, our difficulties would be considerably lessened; while, on the other hand, there can be little doubt, although the reader may, perhaps, smile at the bare suggestion of such an idea, that an amphibious being, who should possess our faculties, would still more easily arrive at sound theoretical opinions in geology, since he might behold, on the one hand, the decomposition of rocks in the atmosphere, or the transportation of matter by running water; and, on the other, examine the deposition of sediment in the sea, and the imbedding of animal and vegetable remains in new strata. He might ascertain, by direct observation, the action of a mountain torrent, as well as of a marine current; might compare the products of volcanos on the land with those poured out beneath the waters; and might mark, on the one hand, the growth of the forest, and on the other that of the coral reef. Yet, even with these advantages, he would be liable to fall into the greatest errors when endeavouring to reason on rocks of subterranean origin. He would seek in vain, within the sphere of his observation, for any direct analogy to the process of their formation, and would therefore be in danger of attributing them, wherever they are upraised to view, to some "primeval state of nature."

But if we may be allowed so far to indulge the imagination, as to suppose a being entirely confined to the nether world—some "dusky melancholy sprite," like Umbriel, who could "flit on sooty pinions to the central earth," but who was never permitted to "sully the fair face of light," and emerge into the regions of water and of air; and if this being should busy himself in investigating the structure of the globe, he might frame theories the exact converse of those usually adopted by human philosophers. He might infer that

the stratified rocks, containing shells and other organic remains, were the oldest of created things, belonging to some original and nascent state of the planet. "Of these masses," he might say, "whether they consist of loose incoherent sand, soft clay, or solid stone, none have been formed in modern times. Every year some part of them are broken and shattered by earthquakes, or melted up by volcanic fire; and, when they cool down slowly from a state of fusion, they assume a new and more crystalline form, no longer exhibiting that stratified disposition, and those curious impressions and fantastic markings, by which they were previously characterized. This process cannot have been carried on for an indefinite time, for in that case all the stratified rocks would long ere this have been fused and crystallized. It is therefore probable that the whole planet once consisted of these mysterious and curiously bedded formations at a time when the volcanic fire had not yet been brought into activity. Since that period there seems to have been a gradual development of heat; and this augmentation we may expect to continue till the whole globe shall be in a state of fluidity and incandescence."

Such might be the system of the Gnome at the very time that the followers of Leibnitz, reasoning on what they saw on the outer surface, would be teaching the opposite doctrine of gradual refrigeration, and averring that the earth had begun its career as a fiery comet, and might be destined hereafter to become a frozen mass. The tenets of the schools of the nether and of the upper world would be directly opposed to each other, for both would partake of the prejudices inevitably resulting from the continual contemplation of one class of phenomena to the exclusion of another.

Man observes the annual decomposition of crystalline and igneous rocks, and may sometimes see their conversion into stratified deposits; but he cannot witness the reconversion of the sedimentary into the crystalline by subterranean fire. He is in the habit of regarding all the sedimentary rocks as more recent than the unstratified, for the same reason that we may suppose him to fall into the opposite error if he saw the origin of the igneous class only.

**ASSUMPTION OF THE DISCORDANCE OF THE ANCIENT
AND EXISTING CAUSES OF CHANGE UNPHILOSOPHICAL.**

It is only by becoming sensible of our natural disadvantages that we shall be roused to exertion, and prompted to seek out opportunities of discovering such of the operations now in progress, as do not present themselves readily to view. We are called upon, in our researches into the state of the earth, as in our endeavours to comprehend the mechanism of the heavens, to invent means for overcoming the limited range of our vision. We are perpetually required to bring, as far as possible, within the sphere of observation, things to which the eye, unassisted by art, could never obtain access.

It was not an impossible contingency, that astronomers might have been placed at some period in a situation much resembling that in which the geologist seems to stand at present. If the Italians, for example, in the early part of the twelfth century, had discovered at Amalphi, instead of the pandects of Justinian, some ancient manuscripts filled with astronomical observations relating to a period of three thousand years, and

made by some ancient geometers who possessed optical instruments as perfect as any in modern Europe, they would probably, on consulting these memorials, have come to a conclusion that there had been a great revolution in the solar and sidereal systems. "Many primary and secondary planets," they might say, "are enumerated in these tables, which exist no longer. Their positions are assigned with such precision, that we may assure ourselves that there is nothing in their place at present but the blue ether. Where one star is visible to us, these documents represent several thousands. Some of those which are now single, consisted then of two separate bodies, often distinguished by different colours, and revolving periodically round a common centre of gravity. There is no analogy to them in the universe at present; for they were neither fixed stars nor planets, but seem to have stood in the mutual relation of sun and planet to each other. We must conclude, therefore, that there has occurred, at no distant period, a tremendous catastrophe, whereby thousands of worlds have been annihilated at once, and some heavenly bodies absorbed into the substance of others." When such doctrines had prevailed for ages, the discovery of one of the worlds, supposed to have been lost, by aid of the first rude telescope invented after the revival of science, would not dissipate the delusion for the whole burden of proof would now be thrown on those who insisted on the stability of the system from a remote period, and these philosophers would be required to demonstrate the existence of *all* the worlds said to have been annihilated.

Such popular prejudices would be most unfavourable to the advancement of astronomy; for, instead of persevering in the attempt to improve their instruments,

and laboriously to make and record observations, the greater number would despair of verifying the continued existence of the heavenly bodies not visible to the naked eye. Instead of confessing the extent of their ignorance, and striving to remove it by bringing to light new facts, they would be engaged in the indolent employment of framing imaginary theories concerning catastrophes and mighty revolutions in the system of the universe.

For more than two centuries the shelly strata of the Subapennine hills afforded matter of speculation to the early geologists of Italy, and few of them had any suspicion that similar deposits were then forming in the neighbouring sea. They were as unconscious of the continued action of causes still producing similar effects, as the astronomers, in the case before supposed, of the existence of certain heavenly bodies still giving and reflecting light, and performing their movements as of old. . Some imagined that the strata, so rich in organic remains, instead of being due to secondary agents, had been so created in the beginning of things by the fiat of the Almighty ; and others ascribed the imbedded fossil bodies to some plastic power which resided in the earth in the early ages of the world. At length Donati explored the bed of the Adriatic, and found the closest resemblance between the new deposits there forming, and those which constituted hills above a thousand feet high in various parts of the peninsula. He ascertained that certain genera of living testacea were grouped together at the bottom of the sea in precisely the same manner as were their fossil analogues in the strata of the hills, and that some species were common to the recent and fossil world. Beds of shells, moreover, in the Adriatic,

were becoming incrustated with calcareous rock: and others were recently enclosed in deposits of sand and clay, precisely as fossil shells were found in the hills. This splendid discovery of the identity of modern and ancient submarine operations was not made without the aid of artificial instruments, which, like the telescope, brought phenomena into view not otherwise within the sphere of human observation.

In like manner, in the Vicentin, a great series of volcanic and marine sedimentary rocks was examined in the early part of the last century; but no geologists suspected before the time of Arduino, that these were partly composed of ancient submarine lavas. If, when these inquiries were first made, geologists had been told that the mode of formation of such rocks might be fully elucidated by the study of processes then going on in certain parts of the Mediterranean, they would have been as incredulous as geometers would have been before the time of Newton, if any one had informed them that, by making experiments on the motion of bodies on the earth, they might discover the laws which regulated the movements of distant planets.

The establishment, from time to time, of numerous points of identification, drew at length from geologists a reluctant admission, that there was more correspondence between the physical constitution of the globe, and more uniformity in the laws regulating the changes of its surface, from the most remote eras to the present, than they at first imagined. If, in this state of the science, they still despaired of reconciling every class of geological phenomena to the operations of ordinary causes, even by straining analogy to the utmost limits of credibility, we might have expected, at least, that the balance of probability would now have

been presumed to incline towards the identity of the causes. But, after repeated experience of the failure of attempts to speculate on different classes of geological phenomena, as belonging to a distinct order of things, each new sect persevered systematically in the principles adopted by their predecessors. They invariably began, as each new problem presented itself, whether relating to the animate or inanimate world, to assume in their theories, that the economy of nature was formerly governed by rules for the most part independent of those now established. Whether they endeavoured to account for the origin of certain igneous rocks, or to explain the forces which elevated hills or excavated valleys, or the causes which led to the extinction of certain races of animals, they first presupposed an original and dissimilar order of nature; and when at length they approximated, or entirely came round to an opposite opinion, it was always with the feeling, that they conceded what they were justified *à priori* in deeming improbable. In a word, the same men who, as natural philosophers, would have been most incredulous respecting any extraordinary deviations from the known course of nature, if reported to have happened *in their own time*, were equally disposed, as geologists, to expect the proofs of such deviations at every period of the past.

I shall now proceed to enumerate some of the principal difficulties still opposed to the theory of the uniformity of the causes which have worked successive changes in the crust of the earth, and in the condition of its living inhabitants. The discussion of so important a question on the present occasion may appear premature, but it is one which naturally arises out of a review of the former history of the science. It is, of course, impos-

sible to enter fully into such speculative topics, without occasionally carrying the novice beyond his depth, and appealing to facts and conclusions with which he must as yet be unacquainted; but his curiosity cannot fail to be excited by having his attention at once called to some of the principal points in controversy, and after reading the second, third, and fourth books, he may return again to these preliminary essays with increased interest and profit.

First, then, it is undeniable, that many objections to the doctrine of the *uniform* agency of geological causes have been partially or entirely removed by the progress of the science in the last forty years. It was objected, for example, to those who endeavoured to explain the formation of sedimentary strata by causes now in diurnal action, that they must take for granted incalculable periods of time. Now the time which they required has since become equally requisite to account for another class of phenomena brought to light by more recent investigations. It must always have been evident to unbiassed minds, that successive strata, containing, in regular order of superposition, distinct beds of shells and corals, arranged in families as they grow at the bottom of the sea, could only have been formed by slow and insensible degrees in a great lapse of ages: yet, until organic remains were minutely examined and specifically determined, it was rarely possible to prove that the series of deposits met with in one country was not formed simultaneously with that found in another. But we are now able to determine, in numerous instances, the relative dates of sedimentary rocks in distant regions, and to show, by their organic remains, that they were not of contemporary origin, but formed in succession. We often find, that

where an interruption in the consecutive formations in one district is indicated by a sudden transition from one assemblage of fossil species to another, the chasm is filled up, in some other district, by other important groups of strata.*

The more attentively we study the European continent, the greater we find the extension of the whole series of geological formations. No sooner does the calendar appear to be completed, and the signs of a succession of physical events arranged in chronological order, than we are called upon to intercalate, as it were, some new periods of vast duration. A geologist, whose observations have been confined to England, is accustomed to consider the superior and newer groups of marine strata in our island as modern,—and such they are, comparatively speaking; but when he has travelled through the Italian peninsula, and in Sicily, and has seen strata of more recent origin forming mountains several thousand feet high, and has marked a long series both of volcanic and submarine operations, all newer than any of the regular strata which enter largely into the physical structure of Great Britain, he returns with more exalted conceptions of the antiquity of some of our modern deposits, than he before entertained of the oldest of the British series.

We cannot reflect on the concessions thus extorted from us, in regard to the duration of past time, without foreseeing that the period may arrive when part of the Huttonian theory will be combated on the ground of its departing too far from the assumption of uniformity in the order of nature. On a closer investigation of extinct volcanos, we find proofs that they broke out

* See Book iv. chap. iii.

at successive eras, and that the eruptions of one group were often concluded long before others had commenced their activity. Some were burning when one class of organic beings were in existence, others came into action when a different and new race of animals and plants existed :— it is more than probable, therefore, that the convulsions caused by subterranean movements, which seem to be merely another portion of the volcanic phenomena, have also occurred in succession ; and their effects must be divided into separate sums, and assigned to separate periods of time. Nor is this all : when we examine the volcanic products, whether they be lavas which flowed out under water, or upon dry land, we find that intervals of time, often of great length, intervened between their formation, and that the effects of single eruptions were not greater in amount than those which now result from ordinary volcanic convulsions. The accompanying or preceding earthquakes, therefore, may be considered to have been also successive, often interrupted by long intervals of time, and not to have exceeded in violence those now experienced in the ordinary course of nature.

Already, therefore, may we regard the doctrine of the sudden elevation of whole continents by paroxysmal eruptions as invalidated ; and there was the greatest inconsistency in the adoption of such a tenet by the Huttonians, who were anxious to reconcile former changes to the present economy of the world. It was contrary to analogy to suppose, that Nature had been at any former epoch parsimonious of time and prodigal of violence — to imagine that one district was not at rest, while another was convulsed — that the disturbing forces were not kept under subjection, so as never to carry simultaneous havoc and desolation over the

whole earth, or even over one great region. If it could have been shown, that a certain combination of circumstances would at some future period produce a crisis in the subterranean action, we should certainly have had no right to oppose our experience for the last three thousand years as an argument against the probability of such occurrences in past ages ; but it is not pretended that such a combination can be foreseen.

In speculating on catastrophes by water, we may certainly anticipate great floods in future, and we may therefore presume that they have happened again and again in past times. The existence of enormous seas of fresh water, such as the North American lakes, the largest of which is elevated more than six hundred feet above the level of the ocean, and is in parts twelve hundred feet deep, is alone sufficient to assure us, that the time may come, however distant, when a deluge may lay waste a considerable part of the American continent. The depression, moreover, of part of Asia, bordering the Caspian Sea, to a depth of from one to three hundred feet below the level of the ocean, might easily give rise to a similar catastrophe.* No hypothetical agency is required to cause the sudden escape of the waters. Such changes of level, and opening of fissures, as have accompanied earthquakes since the commencement of the present century, or such excavation of ravines as the receding cataract of Niagara is now effecting, might breach the barriers. Notwithstanding, therefore, that we have not witnessed within the last three thousand years the devastation by deluge of a large continent, yet, as we may predict the future occurrence of such catastrophes, we are

* See Book iv.

authorized to regard them as part of the present order of Nature; and they may be introduced into geological speculations respecting the past, provided we do not imagine them to have been more frequent or general than we expect them to be in time to come.

The great contrast in the aspect of the older and newer rocks, in their texture, structure, and in the derangement of the strata, appeared formerly one of the strongest grounds for presuming that the causes to which they owed their origin were perfectly dissimilar from those now in operation. But this incongruity may now be regarded as the natural result of subsequent modifications, since the difference of relative age is demonstrated to have been immense, so that, however slow and insensible the change, it must have become important in the course of so many ages. In addition to the influence of volcanic heat, we must allow for the effect of mechanical pressure, of chemical affinity, of percolation by mineral waters, of permeation by elastic fluids, and the action, perhaps, of many other forces less understood, such as electricity and magnetism. In regard to the signs of the upraising, sinking, fracture, and contortion of rocks, it is evident that newer strata cannot be shaken by earthquakes, unless the subjacent rocks are also affected; so that the contrast in the relative degree of disturbance in the more ancient and the newer strata, is one of many proofs that the convulsions have happened in different eras, and the fact confirms the uniformity of the action of subterranean forces, instead of their greater violence in the primeval ages.

Doctrine of Universal Formations. — The popular doctrine of universal formations, or the unlimited geographical extent of strata, distinguished by similar

mineral characters, appeared for a long time to present insurmountable objections to the supposition, that the earth's crust had been formed by causes now acting. If it had merely been assumed, that rocks originating from fusion by subterranean fire presented in all parts of the globe a perfect correspondence in their mineral composition, the assumption would not have been extravagant; for, as the elementary substances that enter largely into the composition of rocks are few in number, they may be expected to arrange themselves invariably in the same forms, whenever the elementary particles are freely exposed to the action of chemical affinities. But when it was imagined that sedimentary mixtures, including animal and vegetable remains, and evidently formed in the beds of ancient lakes and seas, were of a homogeneous nature throughout a whole hemisphere, the dogma precluded at once all hope of recognizing the slightest analogy between the ancient and modern causes of decay and reproduction. We know that existing rivers carry down from different mountain chains sediment of distinct colours and composition: where the chains are near the sea, coarse sand and gravel is swept in; where they are distant, the finest mud. We know, also, that the matter introduced by springs into lakes and seas is very diversified in mineral composition; in short, *contemporaneous* strata now in the progress of formation are greatly varied in their composition, and could never afford formations of homogeneous mineral ingredients co-extensive with the greater part of the earth's surface.

This theory, however, is in truth as inapplicable to the effects of those operations to which the formation of the earth's crust is due, as to the effects of existing

causes. The first investigators of sedimentary rocks had never reflected on the great areas occupied by the modern deltas of large rivers; still less on the much greater areas over which marine currents, preying alike on river-deltas, and continuous lines of sea-coast, diffuse homogeneous mixtures. They were ignorant of the vast spaces over which calcareous and other mineral springs abound upon the land and in the sea, especially in and near volcanic regions, and of the quantity of matter discharged by them. When, therefore, they ascertained the extent of the geographical distribution of certain groups of ancient strata—when they traced them continuously from one extremity of Europe to the other, and found them flanking, throughout their entire range, great mountain chains, they were astonished at so unexpected a discovery; and, considering themselves at liberty to disregard all modern analogy, they indulged in the sweeping generalization, that the law of continuity prevailed throughout strata of contemporaneous origin over the whole planet. The difficulty of dissipating this delusion was extreme, because some rocks, formed under similar circumstances at different epochs, present the same external characters, and often the same internal composition; and all these were assumed to be contemporaneous until the contrary could be shown, which, in the absence of evidence derived from direct superposition, and in the scarcity of organic remains, was often impossible.

Innumerable other false generalizations have been derived from the same source; such, for instance, as the former universality of the ocean, now disproved by the discovery of the remains of terrestrial vegetation

in strata of every age, even the most ancient. But I shall dwell no longer on exploded errors, but proceed at once to contend against weightier objections, which will require more attentive consideration.

CHAPTER VI.

FURTHER EXAMINATION OF THE QUESTION AS TO THE
DISCORDANCE OF THE ANCIENT AND MODERN CAUSES
OF CHANGE.

Proofs that the climate of the Northern Hemisphere was formerly hotter — Direct proofs from the organic remains of the Sicilian and Italian strata — Proofs from analogy derived from extinct Quadrupeds — Imbedding of Animals in Icebergs — Siberian Mammoths — Evidence in regard to temperature, from the fossils of tertiary and secondary rocks — From the Plants of the Coal formation — Northern limit of these fossils — Whether such plants could endure the long continuance of an arctic night.

Climate of the Northern Hemisphere formerly hotter. — THAT the climate of the Northern hemisphere has undergone an important change, and that its mean annual temperature must once have resembled that now experienced within the tropics, was the opinion of some of the first naturalists who investigated the contents of the ancient strata. Their conjecture became more probable when the shells and corals of the secondary rocks were more carefully examined; for these organic remains were found to be intimately connected by generic affinity with species now living in warmer latitudes. At a later period, many reptiles, such as turtles, tortoises, and large saurian animals, were discovered in European formations in great abundance; and they supplied new and powerful arguments, from analogy, in support of the doctrine, that the heat of the climate had been

great when our secondary strata were deposited. Lastly, when the botanist turned his attention to the specific determination of fossil plants, the evidence acquired the fullest confirmation; for the flora of a country is peculiarly influenced by temperature: and the ancient vegetation of the earth might, more readily than the forms of animals, have afforded conflicting proofs, had the popular theory been without foundation. When the examination of animal and vegetable remains was extended to rocks in the most northern parts of Europe and North America, and even to the Arctic regions, indications of the same revolution in climate were discovered.

It cannot be said, that in this, as in many other departments of geology, we have investigated the phenomena of former eras, and neglected those of the present state of things. On the contrary, since the first agitation of this interesting question, the accessions to our knowledge of living animals and plants have been immense, and have far surpassed all the data previously obtained for generalizing, concerning the relation of certain types of organization to particular climates. The tropical and temperate zones of South America and of Australia have been explored; and, on close comparison, it has been found, that scarcely any of the species of the animate creation in these extensive continents are identical with those inhabiting the old world. Yet the zoologist and botanist, well acquainted with the geographical distribution of organic beings in other parts of the globe, would have been able, if distinct groups of species had been presented to them from these regions, to recognize those which had been collected from latitudes within, and those which were brought from without the tropics.

Before I attempt to explain the probable causes of great vicissitudes of temperature on the earth's surface, I shall take a rapid view of some of the principal data which appear to warrant, to the utmost extent, the popular opinions now entertained on the subject. To insist on the soundness of the inference, is the more necessary, because some zoologists have of late undertaken to vindicate the uniformity of the laws of nature, not by accounting for former fluctuations in climate, but by denying the value of the evidence in their favour.*

Direct proofs from the fossil remains of living species.
— It is not merely by reasoning from analogy that we are led to infer a diminution of temperature in the climate of Europe ; there are direct proofs in confirmation of the same doctrine, in the only countries hitherto investigated by expert geologists where we could expect to meet with such proofs. It is not in England or Northern France, but around the borders of the Mediterranean, from the South of Spain to Calabria, and in the islands of the Mediterranean, that we must look for conclusive evidence on this question ; for it is not in strata where the organic remains belong to extinct species, but where living species abound in a fossil state, that a theory of climate can be subjected to the experimentum crucis. In Sicily, Ischia, and Calabria, where the fossil testacea of the more recent strata belong almost entirely to species now inhabiting the Mediterranean, the conchologist remarks, that individuals in the inland deposits often exceed in their average size their living analogues, as if the circum-

* See two articles by the Rev. Dr. Fleming, in the *Edinburgh New Phil. Journ.* No. xii. p. 277., April, 1829 ; and No. xv. p. 65., Jan. 1830.

stances under which they formerly lived were more favourable to their development.* Yet no doubt can be entertained, on the ground of such difference in their dimensions, of their specific identity; because living individuals of many of these species still attain, in warmer latitudes, the average size of the fossils.

As we proceed northwards in the Italian peninsula, and pass from the region of active, to that of extinct volcanos—from districts now violently convulsed from time to time, to those which are comparatively undisturbed by earthquakes, we find the assemblage of fossil shells, in the modern (Subapennine) strata, to depart somewhat more widely from the type of the neighbouring seas. The proportion of species identifiable with those now living in the Mediterranean is still considerable; but it no longer predominates, as in the South of Italy, over the unknown species. Although occurring in localities which are removed several degrees farther from the equator, (as at Sienna, Parma, Asti, &c.) the shells yield clear indications of a hotter climate. Many of them are common to the Subapennine hills, to the Mediterranean, and to the Indian Ocean.

* I collected several hundred species of shells in Sicily, at different elevations, sometimes from one thousand to three thousand feet above the level of the sea, and forty species or more in Ischia, partly from an elevation of above one thousand feet, and these were carefully compared with recent shells procured by Professor O. G. Costa, from the Neapolitan seas. Not only were the fossil species for the most part identical with those now living, but the relative abundance in which different species occur in the strata and in the sea corresponds in a remarkable manner. Yet the larger average size of the fossil individuals of many species was very striking. A comparison of the fossil shells of the more modern strata of Calabria and Otranto, in the collection of Professor Costa, afforded similar results.

Those in the fossil state, and their living analogues from the tropics, correspond in size; whereas the individuals of the same species from the Mediterranean are dwarfish and degenerate, and stunted in their growth, for want of conditions which the Indian Ocean still supplies.*

This evidence amounts to demonstration, and is not neutralized by any facts of a conflicting character; such, for instance, as the association, in the same group, of individuals referrible to species now confined to arctic regions. On the contrary, whenever any of the fossil shells are identified with living species foreign to the Mediterranean, it is not in the Northern Ocean, but between the tropics, that they must be sought.† On

* Professors Guidotti of Parma, and Bonelli of Turin, pointed out to me, in 1828, many examples in confirmation of this point. Among others, I may mention that *Bulla lignaria*, a very common shell, is invariably found fossil in the north of Italy of the same magnitude as it now reaches in the Indian sea, and much smaller in a living state in the Mediterranean. Individuals, however, of this great size are said to have been found at La Rochelle. The common *Orthoceras* of the Mediterranean, *O. raphanista*, attains larger average dimensions in a fossil, than in a recent state.

† Thus, for example, *Rostellaria curvirostris*, found fossil by Signor Bonelli near Turin, is only known at present as an Indian shell. *Murex cornutus*, fossil at Asti, is now only known recent in warmer latitudes, the only localities given by Linnæus and Lamarck being the African and Great Indian Oceans. Senegal is the principal known habitat at present. *Conus antediluvianus* cannot be distinguished from a shell now brought from Owhyhee. Among other familiar instances mentioned to me by Italian naturalists, in confirmation of the same point, *Buccinum clathratum*, Lam., was cited; but Professor Costa assured me that this shell, although extremely rare, still occurs in the Mediterranean. M. Deshayes informs me that he has received it from the Indies.

the other hand, the associated unknown species belong, for the most part, to genera which are now most largely developed in equinoctial regions, as, for example, the genera *Pleurotoma* and *Cypræa*.*

When we proceed to the central and northern parts of Europe, far from the modern theatres of volcanic action, where no considerable inequalities of the earth's surface have been produced, and where few marine strata have been upheaved since the present species were in existence, our opportunities are necessarily more limited of procuring evidence. In such regions it is only in lacustrine deposits, or in ancient river-beds, or in the sand and gravel of land-floods, or the stalagmite of ancient caverns, that we can obtain proofs of the changes which animal life underwent during the deposition of the marine formations before adverted to. We often find, in such situations, the remains of extinct species of quadrupeds, such as the elephant, rhinoceros, hippopotamus, hyæna, and tiger, which belong to genera now confined to warmer regions.

It seems, therefore, fair to infer, that the same change of climate which has caused certain Indian species of testacea to become rare, or to degenerate in size, or to disappear from the Mediterranean,—and certain genera of the Subapennine hills, now exclusively

* Of the genus *Pleurotoma* a very few living representatives have yet been found in the Mediterranean; yet no less than twenty-five species are now to be seen in the museum at Turin, all procured by Professor Bonelli from the Subapennine strata of northern Italy. The genus *Cypræa* is represented by many large fossil species in the Subapennine hills, with which are associated one small and two or three minute species of the same genus, now found in the Mediterranean.

tropical, to retain no longer any representatives in the adjoining seas, — may also have contributed to the annihilation of certain genera of land-mammifera, which inhabited the continents at about the same epoch. The-mammoth (*Elephas primigenius*), and other extinct animals of the same era, may not have required the same temperature as their living congeners within the tropics; but we may infer that the climate was milder than that now experienced in some of the regions once inhabited by them, because, in Northern Russia, where their bones are found in immense numbers, it would be difficult, if not impossible, for such animals to obtain subsistence at present during an arctic winter.

I fully agree with Dr. Fleming, that the kind of food which the existing species of elephant prefers will not enable us to determine, or even to offer a feasible conjecture, concerning that of the extinct species. No one, as he observes, acquainted with the gramineous character of the food of our fallow-deer, stag, or roe, would have assigned a lichen to the rein-deer. But, admitting that the trees and herbage on which the fossil elephants and rhinoceroses may have fed were not of a tropical character, but such perhaps as now grow in the temperate zone, it is still highly improbable that the vegetation which nourished these great quadrupeds was as scanty as that of our arctic regions, or that it was covered during the greater part of every year by snow.

It has been said, that as the modern northern animals migrate, the Siberian elephant and rhinoceros may also have shifted their place to southern latitudes during the inclemency of the season.* That the mam-

* Dr. Fleming, Edin. New Phil. Journ. No. xii. p. 285. April, 1829.

moth continued for a long time to exist in Siberia after the winters had become extremely cold, is demonstrable; since their bones are found in icebergs, and in the frozen gravel, in such abundance as could only have been supplied by many successive generations. So many skeletons could not have belonged to herds which lived at one time in the district, even if those northern countries had once been clothed with vegetation as luxuriant as that of an Indian jungle.

Tilesius, after giving an account of the immense quantity of mammoth's bones which had been procured from the frozen soil of Siberia, justly observes, that the number of elephants now living on the globe must be greatly inferior to those which occur fossil in those northern regions.*

But, if we suppose the change to have been extremely slow, and to have consisted, not so much in a diminution of the mean annual temperature as in an alteration from what has been termed an "insular" to an "excessive" climate,—from one in which the temperature of winter and summer were nearly equalized to one wherein the seasons were violently contrasted,—we may perhaps explain the phenomenon. Siberia and other arctic regions, after having possessed for ages a more uniform temperature, may, after certain changes in the form of the arctic land, to be considered hereafter†, have become occasionally exposed to extremely severe winters. When these first occurred, the valleys may have been, in summer at least, clothed with abundant vegetation; and herds of herbivorous quadrupeds may occasionally have been surprised and

* *Memoirs of the Academy of St. Petersburg*, vol. v.

† See Chap. vii.

buried in snow and ice, by avalanches descending from the higher regions, as often happens to cattle and human beings overwhelmed in the Alpine valleys of Switzerland. If a series of earthquakes accompanied the geographical changes which altered the climate, we may suppose the repetition of such catastrophes to have been indefinite.

That the greater part of the elephants lived in Siberia after it had been subject to intense cold, is confirmed, among other reasons, by the state of the ivory which has been so largely exported in commerce. Its perfect preservation indicates that, from the period when the individuals died, their remains were either buried in a frozen soil, or at least were not exposed to decay in a warm atmosphere. The same conclusion may be deduced from the clothing of the mammoth, of which the entire carcass was discovered by Mr. Adams on the shores of the frozen ocean, near the mouth of the river Lena, inclosed in a mass of ice. The skin of that individual was covered with long hair and with thick wool about an inch in length.*

* Bishop Heber informs us (Narr. of a Journey through the Upper Provinces of India, vol. ii. p. 166—219.), that in the lower range of the Himalaya mountains, in the north-eastern borders of the Delhi territory, between lat. 29° and 30° , he saw an Indian elephant of a small size, covered with shaggy hair. But Mr. Royle (late superintendant of the East India Company's Botanic Garden at Saharumpore) has assured me, that being in India when Heber's Journal appeared, and having never seen or heard of such elephants, he made the strictest inquiries respecting the fact, and was never able to obtain any evidence in corroboration. Mr. Royle resided at Saharumpore, lat. 30° N., upon *the extreme northern limit* of the range of the elephant. Although he found Heber's notes to be full of inaccuracies on botanical and

In regard to the imbedding of mammiferous remains in frozen mud and compact ice, I may observe that, besides the avalanches of snow above alluded to, deep crevices filled with drift snow traverse the glaciers of arctic regions, like the deep rents seen in the *mer de glace* on Mont Blanc. Thus in Spitzbergen, where bears, foxes, and deer abound, the snow collected in such icy fissures is described as being occasionally frozen over on the surface, and hard enough to bear a considerable weight. Dr. Latta relates that, while crossing a glacier in Spitzbergen, one of these treacherous bridges of snow gave way with him, so that he narrowly escaped being precipitated into the body of a glacier.* Dr. Richardson tells me that, in North America, about lat. 65°, he found the carcass of a deer which had fallen into a fissure in a rock, buried in snow, and the flesh, although the animal must have been dead three months, had only become slightly putrescent. In fissures traversing a slippery glacier, these accidents must be frequent whenever herbivorous animals pass over them in their migrations, or hastily cross them when pursued by beasts of prey.

The conversion of drift snow into permanent glaciers and icebergs, when it happens to become covered over with alluvial matter transported by torrents and floods, is by no means a rare phenomenon in the arctic regions. Along the coast, in particular, E. and W. of

other subjects connected with natural history, he does not venture to suppose the Bishop to have been mistaken in regard to the elephant; but it is at least clear that such a variety must be exceedingly rare.

* Edin. New Phil. Journ. No. v. p. 95. June, 1827.

the Mackenzie river, when the sea is frozen over, the snow drifted from the land forms a talus abutting against a perpendicular cliff. On the melting of the snow, torrents rush down from the land, charged with gravel and soil, and, falling over the edge of the cliff, cover the snow, which is often of considerable depth, with alluvium. Water, if any infiltration takes place, is frozen before it penetrates to the bottom of the mass, which is at last consolidated into a compact iceberg, protected from the heat of the sun by a covering of alluvium, on which vegetation often flourishes.

I am indebted to Dr. Richardson for this information, who has seen permanent glaciers forming in this manner in districts of North America now inhabited by many large herbivorous animals. The same process must evidently take place under river-cliffs, as well as along the sea-shore.

Recent investigations have placed beyond all doubt the important fact that a species of tiger, identical with that of Bengal, is common in the neighbourhood of Lake Aral, near Sussac, in the forty-fifth degree of north latitude; and from time to time this animal is now seen in Siberia, in a latitude as far north as the parallel of Berlin and Hamburg.* Humboldt remarks that the part of southern Asia now inhabited by this Indian species of tiger is separated from the Himalaya by two great chains of mountains, each covered with perpetual snow,—the chain of Kuenlun, N. lat. 35°, and that of Mouztagh, lat. 42°,—so that it is impossible that these animals should have merely made excursions from India, so as to have penetrated in summer to the

* Humboldt, *Fragmens de Géologie, &c.* tome ii. p. 388. Ehrenberg, *Ann. des Sci. Nat.*, tome xxi. p. 387.

forty-eighth and fifty-third degrees of north latitude. They must remain all the winter north of the Mouztagh, or Celestial Mountains. The last tiger killed, in 1828, on the Lena, in lat. $52\frac{1}{4}^{\circ}$, was in a climate colder than that of Petersburg and Stockholm.*

A new species also of panther (*Felis irbis*), covered with long hair, has been discovered in Siberia, evidently inhabiting, like the tiger, a region north of the Celestial Mountains, which are in lat. 42° .†

These facts by no means invalidate the inference that the temperature of the northern hemisphere was warmer when the extinct species of elephant, rhinoceros, tiger, hyæna, and other genera, abounded in high latitudes, but they may throw much light on the evidence which geology affords of certain individuals of these races having been enabled to survive down to comparatively modern times. A long series of ages may have intervened between the periods when such species were most flourishing and the era of their final extinction. The mammoth certainly appears to have survived in England when the temperature of our latitudes could not have been very different from that which now prevails; for remains of this animal have been found at North Cliff, in the county of York, in a lacustrine formation, in which all the land and freshwater shells, thirteen in number, can be identified with species and varieties now existing in that county. Bones of the bison also, an animal now inhabiting a cold or temperate climate, have been found in the same place. That these quadrupeds, and the indigenous species of testacea associated with them, were all contemporary inhabitants of Yorkshire, has been established by unequivocal proof. The Rev. W. V. Vernon Harcourt

* Ehrenberg, Ann. des Sci. Nat. tom. xxi. p. 390. † Ibid.

caused a pit to be sunk to the depth of twenty-two feet through undisturbed strata, in which the remains of the mammoth were found imbedded, together with the shells, in a deposit which had evidently resulted from tranquil waters.*

Proofs from analogy of extinct species.—If we pass from the consideration of these more modern deposits, whether of marine or continental origin, in which existing species are abundantly intermixed with the extinct, to the Eocene† or older tertiary strata, we can only reason from analogy; since none of the species of vertebrated animals, and scarcely any of the testacea of those formations, are identifiable with species now in being. In the deposits of that more remote period, we find the remains of many animals analogous to those of hot climates, such as the crocodile, turtle, and tortoise, together with many large shells of the genus nautilus, and plants indicating such a temperature as is now found along the southern borders of the Mediterranean.

A great interval of time appears to have elapsed between the deposition of the last-mentioned Eocene strata, and the *secondary* formations, which constitute the principal portion of the more elevated land in Europe. In these secondary rocks a very distinct assemblage of organized fossils are entombed, all of unknown species, and many of them referrible to genera and families now most abundant between the tropics. Among the most remarkable are many gigantic reptiles, some of them herbivorous, others carnivorous, and far exceeding in size any now known

* Phil. Mag. Sept. 1829 and Jan. 1830.

† See Book iv. ch. v.

even in the torrid zone. The genera are for the most part extinct, but some of them, as the crocodile and monitor, have still representatives in the warmer parts of the earth. Coral reefs also were evidently numerous in the seas of the same period, and composed of species belonging to genera now characteristic of a tropical climate. The number of immense chambered shells also leads us to infer an elevated temperature; and the associated fossil plants, although imperfectly known, tend to the same conclusion, the Cycadeæ constituting the most numerous family.

But the study of the more ancient coal deposits has yielded the most extraordinary evidence of an extremely hot climate; for it appears from the fossils of that period that the flora consisted almost exclusively of large vascular cryptogamic plants. We learn, from the labours of M. Ad. Brongniart, that there existed at that epoch *Equiseta* upwards of ten feet high, and from five to six inches in diameter; tree ferns, or plants allied to them, of from forty to fifty feet in height, and arborescent *Lycopodiaceæ*, of from sixty to seventy feet high.* Of the above classes of vegetables, the species are all small at present in cold climates; while in tropical regions there occur, together with small species, many of a much greater size, but their development at present, even in the hottest parts of the globe, is inferior to that indicated by the petrified forms of the coal formation. An elevated and uniform temperature, and great humidity in the air, are the causes most favourable for the numerical predominance and the great size of these plants within the torrid zone at present. It is

* *Consid. Générales sur la Nature de la Végétation, &c.* Ann. des Sci. Nat., Nov. 1828.

true that as the fossil flora consists of such plants as may accidentally have been floated into seas, lakes, or estuaries, it may often, perhaps always, give a false representation of the numerical relations of families then living on the land. Yet, after allowing for all liability to error on these grounds, the argument founded on the comparative numbers of the fossil plants of the carboniferous strata is very strong.

“In regard to the geographical extent of the ancient vegetation, it was not confined,” says M. Brongniart, “to a small space, as to Europe, for example; for the same forms are met with again at great distances. Thus, the coal plants of North America are, for the most part, identical with those of Europe, and all belong to the same genera. Some specimens, also, from Greenland are referrible to ferns, analogous to those of our European coal mines; and it appears, from the description of those brought from Baffin’s Bay by Captain Parry, but which I have not examined myself, that they belong to very similar species.”*

The fossil plants brought from Melville Island, although in a very imperfect state, have been supposed to warrant similar conclusions†; and assuming that they should agree with those of Baffin’s Bay, mentioned by M. Brongniart, how shall we explain the manner in which such a vegetation lived through an arctic night of several months’ duration?‡

* *Prodrome d’une Hist. des Végét. Foss.* p. 179.

† König, *Journ. of Sci.* vol. xv. p. 20. Mr. König informs me, that he no longer believes any of these fossils to be tree ferns, as he at first stated, but that they agree with tropical forms of plants in our English coal-beds. The Melville Island specimens, now in the British Museum, are very obscure impressions.

‡ *Fossil Flora of Great Britain*, by John Lindley and William Hutton, Esqrs. No. IV.

This point has of late been dwelt upon by Professor Lindley, as one of considerable difficulty* ; and he is even fain to resort again to the favourite hypothesis of earlier theorists — a derangement in the position of the earth's axis of rotation. But all astronomers are agreed that speculations on such a change are inadmissible, as being incompatible with the laws of equilibrium. Even if a catastrophe, such as the collision of a comet, be called in, and admitted as adequate to alter the obliquity of the axis, the problem is by no means solved ; for in that case the seas would have all rushed to the new equator, and would probably still be insufficient to restore equilibrium.† The bulge, also, of the ancient equator ought still to be visible, crossing the present Line at two points, whereas no such irregularity exists in the form of the spheroid.

It may seem premature to discuss the question now raised, until more accurate determinations have been made respecting the true nature of the fossil flora of the arctic regions ; yet, as the question has attracted some attention, let us assume for a moment, that the coal plants of Melville Island are strictly analogous to those of Northumberland — would such a fact present an inexplicable enigma to the vegetable physiologist ?

Plants, it is affirmed, cannot be retained in darkness, even for a week, without serious injury, unless in a torpid state ; and if exposed to heat and moisture they cannot remain torpid, but will grow, and must therefore perish. If, then, in the latitude of Melville Island, 75° N., a high temperature, and consequent humidity,

* Fossil Flora, No. IV. ; and in his Lectures. Mr. Lindley tells me, however, that he has not yet (Oct. 1838) had opportunities of examining the fossil plants of high latitudes.

† Mrs. Somerville's *Mech. of Heavens*, Prel. Disc. p. 38.

prevailed at that period when we know the arctic seas were filled with corals and large multilocular shells, how could plants of tropical forms have flourished? Is not the bright light of equatorial regions as indispensable a condition of their well-being as the sultry heat of the same countries? and how could they annually endure a night prolonged for three months? *

Now, we must bear in mind, in the first place, that, so far as experiments have been made, there is every reason to conclude, that the range of intensity of light to which living plants can accommodate themselves is far wider than that of heat. No palms or tree-ferns can live in our temperate latitudes without protection from the cold, but when placed in hot-houses they grow luxuriantly, even under a cloudy sky, and where much light is intercepted by the glass and framework. At St. Petersburg, in lat. 60° N., these plants have been successfully cultivated in hot-houses, although here they must exchange the perpetual equinox of their native regions for days and nights which at certain seasons are protracted to nineteen hours, at others shortened to five. How much farther towards the pole they might continue to live, provided a due quantity of heat and moisture were supplied, has not yet been determined; but St. Petersburg is probably not the utmost limit, and we should expect that in lat. 65° at least, where they would never remain twenty-four hours without enjoying the sun's light, they might still exist.

Nor must we forget that we are always speaking of *living* species formed to inhabit within or near the tropics. The coal plants were of perfectly distinct

* Fossil Flora, No. IV.

species, and may have been endowed with a different constitution, enabling them to bear a greater variation of circumstances in regard to light. We find that particular species of palms and tree ferns require at present different degrees of heat; and that some species can thrive only in the immediate neighbourhood of the equator, others only at a distance from it. In the same manner the *minimum* of *light*, sufficient for the now existing species, cannot be taken as the standard for all analogous tribes that may ever have flourished on the globe.

But should we concede, for the sake of argument, that the extreme northern point to which a flora like that of the carboniferous era could ever reach may be somewhere between the latitudes of 65° and 70° , we should still have to inquire whether the vegetable remains might not have been drifted from thence, by rivers and currents, to the parallel of Melville Island, or still farther. In the northern hemisphere, at present, we see that the materials for future beds of lignite and coal are becoming amassed in high latitudes, far from the districts where the forests grew, and on shores where scarcely a stunted shrub can now exist. The Mackenzie, and other rivers of North America, carry pines with their roots attached for many hundred miles towards the north, into the arctic sea, where they are imbedded in deltas, and some of them drifted still farther by currents towards the pole.

Some of the appearances of our English coal fields seem to prove that the plants were not floated from great distances; for the outline of the stems of succulent species preserve their sharp angles, and others have their surfaces marked with the most delicate lines and streaks. Long leaves, also, are attached in many in-

stances to the trunks or branches* ; and leaves we know, in general, are soon destroyed when steeped in water, although ferns will retain their forms after an immersion of several months.† It seems fair to presume that the coal plants may have grown upon the same land, the destruction of which provided materials for the sandstones and conglomerates of the group of strata in which they are imbedded ; especially as the coarseness of the particles of many of these rocks attests that they were not borne from very remote localities.

Before we are entitled to enlarge farther on this question of transportation, we must obtain more precise information respecting the state of the various fossils which have been found principally in the coal sandstones of high latitudes, and we must learn whether they bear the marks of friction and decay previous to their fossilization.

To return, therefore, from our digression, the uninjured corals and chambered univalves of Iglulic, Melville Island, and other high latitudes, sufficiently prove that during the carboniferous period, there was an elevated temperature even in northern regions bordering on the arctic circle. The heat and humidity of the air, and the uniformity of climate, appear to have been most remarkable when the oldest strata hitherto discovered were formed. The approximation to a climate similar to that now enjoyed in these latitudes does not commence till the era of the formations termed tertiary ; and while the different tertiary rocks were deposited

* Fossil Flora, No. X.

† This has been proved by Mr. Lindley, who is now conducting a series of experiments on the subject.

in succession, the temperature seems to have been still further lowered, and to have continued to diminish gradually, even after the appearance upon the earth of a great portion of the existing species.

CHAPTER VII.

FURTHER EXAMINATION OF THE QUESTION AS TO THE
DISCORDANCE OF THE ANCIENT AND MODERN CAUSES
OF CHANGE.

On the causes of vicissitudes in climate — Remarks on the present diffusion of heat over the globe — On the dependence of the mean temperature on the relative position of land and sea — Isothermal lines — Currents from equatorial regions — Drifting of icebergs — Different temperature of Northern and Southern hemispheres — Combination of causes which might produce the extreme cold of which the earth's surface is susceptible — Conditions necessary for the production of the extreme of heat, and its probable effects on organic life.

Causes of vicissitudes in Climate. — As the proofs enumerated in the last chapter indicate that the earth's surface has experienced great changes of climate since the deposition of the older sedimentary strata, we have next to inquire, how such vicissitudes can be reconciled with the existing order of nature. The cosmogonist has availed himself of this, as of every obscure problem in geology, to confirm his views concerning a period when the laws of the animate and inanimate world differed essentially from those now established; and he has in this, as in all other cases, succeeded so far, as to divert attention from that class of facts, which, if fully understood, might probably lead to an explanation of the phenomenon. At first it was imagined that the earth's axis had been for ages perpendicular to the plane of the ecliptic, so that there was a perpetual equinox, and unity of seasons throughout

the year ; — that the planet enjoyed this '*paradisiacal*' state until the era of the great flood ; but in that catastrophe, whether by the shock of a comet, or some other convulsion, it lost its equal poise, and hence the obliquity of its axis, and with that the varied seasons of the temperate zone, and the long nights and days of the polar circles.

When the advancement of astronomical science had exploded this theory, it was assumed, that the earth at its creation was in a state of fluidity, and red hot, and that ever since that era it had been cooling down, contracting its dimensions, and acquiring a solid crust, — an hypothesis equally arbitrary, but more calculated for lasting popularity, because, by referring the mind directly to the beginning of things, it requires no support from observation, nor from any ulterior hypothesis.

They who are satisfied with this solution are relieved from all necessity of inquiry into the present laws which regulate the diffusion of heat over the surface ; for, however well these may be ascertained, they cannot possibly afford a full and exact elucidation of the internal changes of an embryo world. As well might a naturalist, by merely studying the plumage and external forms of full-fledged birds, hope to divine the colour of their eggs, or the mysterious metamorphoses of the yolk during incubation.

But if, instead of vague conjectures as to what might have been the state of the planet at the era of its creation, we fix our thoughts steadily on the connexion at present between climate and the distribution of land and sea ; and if we then consider what influence former fluctuations in the physical geography of the earth must have had on superficial temperature, we may perhaps approximate to a true theory. If doubt

still remain, it should be ascribed to our ignorance of the laws of Nature, not to revolutions in her economy ; — it should stimulate us to further research, not tempt us to indulge our fancies in framing imaginary systems for the government of infant worlds.

Laws governing the diffusion of heat over the globe. — In considering the laws which regulate the diffusion of heat over the globe, says Humboldt, we must beware not to regard the climate of Europe as a type of the temperature which all countries placed under the same latitude enjoy. The physical sciences, observes this philosopher, always bear the impress of the places where they began to be cultivated ; and as, in geology, an attempt was at first made to refer all the volcanic phenomena to those of the volcanos in Italy, so, in meteorology, a small part of the old world, the centre of the primitive civilization of Europe, was for a long time considered a type to which the climate of all corresponding latitudes might be referred. But this region, constituting only one seventh of the whole globe, proved eventually to be the exception to the general rule ; and for the same reason we may warn the geologist to be on his guard, and not hastily to assume that the temperature of the earth in the present era is a type of that which most usually obtains, since he contemplates far mightier alterations in the position of land and sea, at different epochs, than those which now cause the climate of Europe to differ from that of other countries in the same parallels.

It is now well ascertained that zones of equal warmth, both in the atmosphere and in the waters of the ocean, are neither parallel to the equator nor to

each other.* It is also discovered that the same mean annual temperature may exist in two places which enjoy very different climates, for the seasons may be nearly equalized or violently contrasted. Thus the lines of equal winter temperature do not coincide with the lines of equal annual heat, or isothermal lines. The deviations of all these lines from the same parallel of latitude are determined by a multitude of circumstances, among the principal of which are the position, direction, and elevation of the continents and islands, the position and depths of the sea, and the direction of currents and of winds.

It is necessary to go northwards in Europe in order to find the same mean quantity of annual heat as in a similar latitude in North America. On comparing these two continents, it is found that places situated in the same latitudes have sometimes a mean difference of temperature amounting to 11° , or even sometimes 17° , of Fahrenheit; and places on the two continents, which have the same mean temperature, have sometimes a difference in latitude of from 7° to 13° .† The principal cause of greater intensity of cold in corresponding latitudes of North America and Europe, is the connexion of the former country with the polar circle, by a large tract of land, some of which

* We are indebted to Baron Alex. Humboldt for collecting together, in a beautiful essay, the scattered data on which some approximation to a true theory of the distribution of heat over the globe may be founded. Many of these data are derived from the author's own observations, and many from the works of M. Prevost on the radiation of heat, and other writers. — See Humboldt on Isothermal Lines, *Mémoires d'Arcueil*, tom. iii. translated in the *Edin. Phil. Journ.* vol. iii. July, 1820.

† Humboldt's tables, *Essay on Isothermal Lines*, &c.

is from three to five thousand feet in height, and, on the other hand, the separation of Europe from the arctic circle by an ocean. The ocean has a tendency to preserve every where a mean temperature, which it communicates to the contiguous land, so that it tempers the climate, moderating alike an excess of heat or cold. The elevated land, on the other hand, rising to the colder regions of the atmosphere, becomes a great reservoir of ice and snow, attracts, condenses, and congeals vapour, and communicates its cold to the adjoining country. For this reason, Greenland, forming part of a continent which stretches northward to the 82d degree of latitude, experiences under the 60th parallel a more rigorous climate than Lapland under the 72d parallel.

But if land be situated between the 40th parallel and the equator, it produces, unless it be of extreme height, exactly the opposite effect, for it then warms the tracts of land or sea that intervene between it and the polar circle. For the surface being in this case exposed to the vertical, or nearly vertical rays of the sun, absorbs a large quantity of heat, which it diffuses by radiation into the atmosphere. For this reason, the western parts of the old continent derive warmth from Africa, "which, like an immense furnace," says Malte-Brun*, "distributes its heat to Arabia, to Turkey in Asia, and to Europe." On the contrary, Asia, in its north-eastern extremity, experiences in the same latitude extreme cold; for it has land on the north between the 60th and 70th parallel, while to the south it is separated from the equator by the North Pacific.

In consequence of the more equal temperature of the

* Phys. Geog. book xvii.

waters of the ocean, the climate of islands and coasts differs essentially from that of the interior of continents, the former being characterized by mild winters and more temperate summers : for the sea breezes moderate the cold of winter, as well as the summer heat. When, therefore, we trace round the globe those belts in which the mean annual temperature is the same, we often find great differences in climate ; for there are *insular* climates where the seasons are nearly equalized, and *excessive* climates, as they have been termed, where the temperature of winter and summer is strongly contrasted. The whole of Europe, compared with the eastern parts of America and Asia, has an insular climate. The northern part of China, and the Atlantic region of the United States, exhibit “excessive climates.” We find at New York, says Humboldt, the summer of Rome and the winter of Copenhagen ; at Quebec, the summer of Paris and the winter of Petersburgh. At Pekin, in China, where the mean temperature of the year is that of the coasts of Brittany, the scorching heats of summer are greater than at Cairo, and the winters as rigorous as at Upsal.*

If lines be drawn round the globe through all those places which have the same winter temperature, they are found to deviate from the terrestrial parallels much farther than the lines of equal mean annual heat. The lines of equal winter in Europe, for example, are often curved so as to reach parallels of latitude 9° or 10° distant from each other, whereas the isothermal lines only differ from 4° to 5° .

Influence of currents on temperature.— Among other influential causes, both of remarkable diversity in the

* On Isothermal Lines.

mean annual heat, and of unequal division of heat in the different seasons, are the direction of currents and the accumulation and drifting of ice in high latitudes. That most powerful current, called in one part of its course the Gulf stream, after doubling the Cape of Good Hope, flows to the northward along the western coast of Africa, then crosses the Atlantic, and accumulates in the Gulf of Mexico. It then issues through the Straits of Bahama, running northwards at the rate of four miles an hour, and retains in the parallel of 38° , nearly one thousand miles from the above strait, a temperature 10° Fahrenheit warmer than the air.

The general climate of Europe is materially affected by the volume of warmer water thus borne northwards; for it maintains an open sea free from ice in the meridian of East Greenland and Spitzbergen, and thus moderates the cold of all the lands lying to the south. Until the waters of the great current reach the circumpolar sea, their specific gravity is less than that of the lower strata of water; but when they arrive near Spitzbergen, they meet with the water of melted ice, which being nearly fresh is still lighter, for it is a well-known law of this fluid, that it passes the point of greatest density when cooled down below 40° , and between that and the freezing point expands again.*

* Scoresby's Arctic Regions, vol. i. p. 210. From the circumstance of an understratum of water in the Spitzbergen sea being generally warmer by some degrees than at the surface, "though of similar specific gravity," Scoresby infers that "the warmer water is in this case the most dense, or why does it not rise and change places with the colder water at the surface?" But Erman (Poggendorf's Annalen, 1828, vol. xii. p. 483.) has proved by experiment, that sea-water does not follow the same law as fresh water, as De Luc, Rumford, and Marcet supposed. On the contrary,

The great glaciers generated in the valleys of Spitzbergen, in the 79° of north latitude, are almost all cut off at the beach, being melted by the feeble remnant of heat retained by the Gulf stream. In Baffin's Bay, on the contrary, on the east coast of Old Greenland, where the temperature of the sea is not mitigated by the same cause, and where there is no warmer under-current, the glaciers stretch out from the shore, and furnish repeated crops of mountainous masses of ice which float off into the ocean.* The number and dimensions of these bergs is prodigious. Captain Ross saw several of them together in Baffin's Bay aground in water fifteen hundred feet deep! Many of them are driven down into Hudson's Bay, and accumulating there, diffuse excessive cold over the neighbouring continent; so that Captain Franklin reports, that at the mouth of Hayes river, which lies in the same latitude as the north of Prussia or the south of Scotland, ice is found every where in digging wells, in summer, at the depth of four feet!

Difference of climate of the Northern and Southern hemispheres.—When we compare the climate of the northern and southern hemispheres, we obtain still more instruction in regard to the influence of the distribution of land and sea on climate. The dry land in the southern hemisphere is to that of the northern in

it appears that salt water of sp. gr. 1.027 (which according to Berzelius is the mean density of sea water) has *no maximum of density* so long as it remains fluid; and even when ice begins to form in it, the remaining fluid part always increases in density in proportion to the degree of refrigeration.

* Scoresby's Arctic Regions, vol. i. p. 208. — Dr. Latta's Observations on the Glaciers of Spitzbergen, &c. Edin. New Phil. Journ. vol. iii. p. 97.

the ratio only of one to three, excluding from our consideration that part which lies between the pole and the 74° of south latitude, which has hitherto proved inaccessible. The predominance of ice in the antarctic over the arctic zone is very great; for that which encircles the southern pole, extends to lower latitudes by ten degrees than that around the north pole.* It is probable that this remarkable difference is partly attributable, as Cook conjectured, to the existence of a considerable tract of high land between the 70th parallel of south latitude and the pole. There is, however, another reason suggested by Humboldt, to which great weight is due,—the small quantity of land in the tropical and temperate zones south of the line. If Africa and New Holland extended farther to the south, a diminution of ice would take place in consequence of the radiation of heat from these continents during summer, which would warm the contiguous sea and rarefy the air. The heated aerial currents would then ascend and flow more rapidly towards the south

* Captain Weddell, in 1823, reached 3° farther than Captain Cook, and arrived at lat. $74^{\circ} 15'$ south, lon. $34^{\circ} 17'$ west. After having passed through a sea strewed with numerous ice islands, he arrived, in that high latitude, at an open ocean; but even if he had sailed 6° farther south, he would not have penetrated to higher latitudes than Captain Parry in the arctic circle, who reached lat. $81^{\circ} 10'$ north. Captain Biscoe, in his late voyage in 1831 and 1832, discovered Graham's Land between 64° and 68° S. lat., to the southward of New South Shetland, and Enderby's Land in the same latitude, in the meridian of Madagascar. These observations heighten the presumption that the prevalence of ice in the southern hemisphere arises, as Captain Cook supposed, from the existence of more extensive or loftier tracts of land in the antarctic than in the arctic regions. Journ. of Roy. Geograph. Soc. of London, 1833.

pole, and moderate the winter. In confirmation of these views, it is stated that the cap of ice, which extends as far as the 68° and 71° of south latitude, advances more towards the equator whenever it meets a free sea; that is, wherever the extremities of the present continents are not opposite to it; and this circumstance seems explicable only on the principle above alluded to, of the radiation of heat from the lands so situated.

Before the amount of difference between the temperature of the two hemispheres was ascertained, it was referred by many astronomers to the acceleration of the earth's motion in its perihelium; in consequence of which the spring and summer of the southern hemisphere are shorter, by nearly eight days, than those seasons north of the equator. But Sir J. Herschel reminds us that the excess of eight days in the duration of the sun's presence in the northern hemisphere is not productive of an excess of annual light and heat; since, according to the laws of elliptic motion, it is demonstrable that whatever be the ellipticity of the earth's orbit, the two hemispheres must receive *equal absolute quantities* of light and heat per annum, the proximity of the sun in perigee exactly compensating the effect of its swifter motion.* Humboldt†, however, observes,

* This follows, observes Herschel, from a very simple theorem, which may be thus stated: — "The amount of heat received by the earth from the sun, while describing any part of its orbit, is proportional to the angle described round the sun's centre." So that if the orbit be divided into two portions by a line drawn in *any direction* through the sun's centre, the heats received in describing the two unequal segments of the ellipse so produced will be equal. Geol. Trans. vol. iii. part ii. p. 298.; second series.

† On Isothermal Lines.

that the accumulation of heat in the southern hemisphere must be less on account of the greater emission of radiant heat, which continues during a winter longer by eight days than that on the other side of the equator. Perhaps no very sensible effect may be produced by this source of disturbance, yet the geologist should bear in mind that to a certain extent it operates alternately on each of the two hemispheres for a period of upwards of 10,000 years, dividing unequally the times during which the annual supply of solar light and heat is received. This cause may sometimes tend to counterbalance inequalities of temperature resulting from other far more influential circumstances ; but, on the other hand, it must sometimes tend to increase the extreme of deviation arising from certain combinations of causes.

But, whatever may now be the inferiority of heat in the temperate and frigid zones south of the line, it is quite evident that the cold would be far more intense if there happened, instead of open sea, to be tracts of elevated land between the 55th and 70th parallel ; for, in Sandwich land, in 59° of south latitude, the perpetual snow and ice reach to the sea beach ; and what is still more astonishing, in the island of Georgia, which is in the 54° south latitude, or the same parallel as the county of Yorkshire, the perpetual snow descends to the level of the ocean. When we consider this fact, and then recollect that the summit of the highest mountains in Scotland, four degrees farther to the north, do not attain the limit of perpetual snow on this side of the equator, we learn that latitude is one only of many powerful causes, which determine the climate of particular regions of the globe. The permanence of snow in the southern hemisphere, in this instance, is partly due to the floating ice, which chills the atmo-

sphere and condenses the vapour, so that in summer the sun cannot pierce through the foggy air. But besides the abundance of ice, from whatever cause derived, which covers the sea to the south of Georgia and Sandwich land, we must also ascribe the cold of those countries in part to the absence of land between them and the tropics.

The distance to which icebergs float from the polar regions on the opposite sides of the line is, as might have been anticipated, very different. Their extreme limit in the northern hemisphere appears to be the Azores (north latitude 42°), to which isles they are sometimes drifted from Baffin's Bay. But in the other hemisphere they have been seen, within the last few years, at different points off the Cape of Good Hope, between latitude 36° and 39° .* One of these was two miles in circumference, and 150 feet high.† Others rose from 250 to 300 feet above the level of the sea, and were therefore of great volume below; since it is ascertained, by experiments on the buoyancy of ice floating in sea-water, that for every solid foot seen above, there must at least be eight feet below water.‡ If ice-islands from the north polar regions floated as far, they might reach Cape St. Vincent, and then, being drawn by the current that always sets in from the Atlantic through the Straits of Gibraltar, be drifted into the Mediterranean, so that the serene sky of that delightful region might be deformed by clouds and mists.

The great extent of sea gives a particular character

* On Icebergs in low Latitudes, by Captain Horsburgh; read to the Royal Society, February, 1830.

† Edin. New Phil. Journ. No. xv. p. 193.; January, 1830.

‡ Scoresby's Arctic Regions, vol. i. p. 234.

to climates south of the equator, the winters being mild and the summers cold. Thus, in Van Diemen's land, corresponding nearly in latitude to Rome, the winters are more mild than at Naples, and the summers not warmer than those at Paris, which is 7° farther from the equator.* The effect on vegetation is very remarkable: — tree-ferns, for instance, which require abundance of moisture, and an equalization of the seasons, are found in Van Diemen's land in latitude 42° , and in New Zealand in south latitude 45° . The orchideous parasites also advance towards the 38° and 42° of south latitude. These forms of vegetation might perhaps be developed in still higher latitudes, if the ice in the antarctic circle did not extend farther from the pole than in the arctic. Humboldt observes that it is in the *mountainous, temperate, humid, and shady* parts of the equatorial regions, that the family of ferns produces the greatest number of species. As we know, therefore, that elevation often compensates the effect of latitude in plants, we may easily understand that a class of vegetables, which grow at a certain height in the torrid zone, would flourish on the plains far from the equator, provided the temperature, moisture, and other necessary conditions, were equally uniform throughout the year.

Changes in the position of land and sea may give rise to vicissitudes in climate. — Having offered these brief remarks on the diffusion of heat over the globe in the present state of the surface, I shall now proceed to speculate on the vicissitudes of climate, which must attend those endless variations in the geographical features of our planet which are contemplated in geology. That our speculations may be confined within

* Humboldt on Isothermal Lines.

the strict limits of analogy, I shall assume, 1st, That the proportion of dry land to sea continues always the same. 2dly, That the volume of the land rising above the level of the sea is a constant quantity; and not only that its mean, but that its extreme height, are only liable to trifling variations. 3dly, That both the mean and extreme depth of the sea are equal at every epoch; and, 4thly, It will be consistent with due caution to assume that the grouping together of the land in great continents is a necessary part of the economy of nature; for it is possible that the laws which govern the subterranean forces, and which act simultaneously along certain lines, cannot but produce, at every epoch, continuous mountain-chains; so that the subdivision of the whole land into innumerable islands may be precluded.

If it be objected, that the maximum of elevation of land and depth of sea are probably not constant, nor the gathering together of all the land in certain parts, nor even perhaps the relative extent of land and water, I reply, that the arguments about to be adduced will be strengthened, if, in these peculiarities of the surface, there be considerable deviations from the present type. If, for example, all other circumstances being the same, the land is at one time more divided into islands than at another, a greater uniformity of climate might be produced, the mean temperature remaining unaltered: or if, at another era, there were mountains higher than the Himalaya, these, when placed in high latitudes, would cause a greater excess of cold. So, if we suppose that at certain periods no chain of hills in the world rose beyond the height of 10,000 feet, a greater heat might then have prevailed than is compatible with the existence of mountains thrice that elevation.

However constant may be the relative proportion of sea and land, we know that there is annually some small variation in their respective geographical positions, and that in every century the land is in some parts raised, and in others depressed by earthquakes; and so likewise is the bed of the sea. By these and other ceaseless changes, the configuration of the earth's surface has been remodelled again and again since it was the habitation of organic beings, and the bed of the ocean has been lifted up to the height of some of the loftiest mountains. The imagination is apt to take alarm when called upon to admit the formation of such irregularities in the crust of the earth, after it had once become the habitation of living creatures; but, if time be allowed, the operation need not subvert the ordinary repose of nature, and the result is insignificant if we consider how slightly the highest mountain-chains cause our globe to differ from a perfect sphere. Chimborazo, although it rises to more than 21,000 feet above the surface of the sea, would only be represented, on an artificial globe of about six feet in diameter, by a grain of sand less than one twentieth of an inch in thickness.*

The superficial inequalities of the earth, then, may be deemed minute in quantity, and their distribution at any particular epoch must be regarded in geology as temporary peculiarities, like the height and outline of the cone of Vesuvius in the interval between two eruptions. But, although the unevenness of the surface is so unimportant in reference to the magnitude of the globe, it is on the position and direction of these small inequalities that the state of the atmosphere, and both the local and general climate, are mainly dependent.

* Malte-Brun's System of Geography, book i. p. 6.

Before considering the effect which a material change in the distribution of land and sea must occasion, it may be well to remark, how greatly organic life may be affected by those minor mutations, which need not in the least degree alter the general temperature. Thus, for example, if we suppose, by a series of convulsions, a certain part of Greenland to become sea, and, in compensation, a tract of land to rise and connect Spitzbergen with Lapland,—an accession not greater in amount than one which the geologist can prove to have occurred in certain districts bordering the Mediterranean, within a comparatively modern period,—this altered form of the land might occasion an interchange between the climate of certain parts of North America and of Europe, which lie in corresponding latitudes. Many European species would probably perish in consequence, because the mean temperature would be greatly lowered; and others would fail in America, because it would there be raised. On the other hand, in places where the mean annual heat remained unaltered, some species which flourish in Europe, where the seasons are more uniform, would be unable to resist the great heat of the North American summer, or the intense cold of the winter; while others, now fitted by their habits for the great contrast of the American seasons, would not be fitted for the *insular* climate of Europe. The vine, for example, according to Humboldt, can be cultivated with advantage 10° farther north in Europe than in North America. Many plants will endure a severe frost, but cannot ripen their seeds without a certain intensity of summer heat and a certain quantity of light; others cannot endure a similar intensity either of heat or cold.

It is now established that many species of animals,

which are at present the contemporaries of man, have survived great changes in the physical geography of the globe. If such species be termed modern, in comparison to races which preceded them, their remains, nevertheless, enter into submarine deposits many hundred miles in length, and which have since been raised from the deep to no inconsiderable altitude. When, therefore, it is shown that changes of the temperature of the atmosphere may be the consequence of such physical revolutions of the surface, we ought no longer to wonder that we find the distribution of existing species to be *local*, in regard to *longitude* as well as latitude. If all species were now, by an exertion of creative power, to be diffused uniformly throughout those zones where there is an equal degree of heat, and in all respects a similar climate, they would begin from this moment to depart more and more from their original distribution. Aquatic and terrestrial species would be displaced, as Hooke long ago observed, so often as land and water exchanged places; and there would also, by the formation of new mountains and other changes, be transpositions of climate, contributing, in the manner before alluded to, to the local extermination of species.*

If we now proceed to consider the circumstances required for a *general* change of temperature, it will appear, from the facts and principles already laid down, that whenever a greater extent of high land is collected in the polar regions, the cold will augment; and the same result will be produced when there shall be more sea between or near the tropics; while, on the contrary,

* For a full consideration of the effect of changes in physical geography on the distribution and extinction of species, see book iii.

so often as the above conditions are reversed, the heat will be greater. If this be admitted, it will follow as a corollary, that unless the superficial inequalities of the earth be fixed and permanent, there must be never-ending fluctuations in the mean temperature of every zone; and that the climate of one era can no more be a type of every other, than is one of our four seasons of all the rest.

It has been well said, that the earth is covered by an ocean, and in the midst of this ocean there are two great islands, and many smaller ones; for the whole of the continents and islands occupy an area scarcely exceeding one fourth of the whole superficies of the spheroid. Now, on a fair calculation, we may expect that at any given epoch there will not be more than about one fourth dry land in a particular region; such, for example, as the arctic and antarctic circles. If, therefore, at present there should happen, in the only one of these regions which we can explore, to be much more than this average proportion of land, and some of it above five thousand feet in height, this alone affords ground for concluding that, in the present state of things, the mean heat of the climate is below that which the earth's surface, in its more ordinary state, would enjoy. This presumption is heightened, when we remember that the mean depth of the Atlantic ocean is calculated to be about three miles, and that of the Pacific four miles*; so that we might look not

* See Young's Nat. Phil. Lect. xlvii.; Mrs. Somerville's Mechanism of Heav., Prel. Dis. p. xxxix. Laplace seems often to have changed his opinion, reasoning from the depth required to account for the phenomena of the tides; but his final conclusion respecting the sea was "*que sa profondeur moyenne est du même ordre que la hauteur moyenne des continens et des îles au-dessus de son*

only for more than two thirds sea in the frigid zones, but for water of great depth, which could not readily be reduced to the freezing point. The same opinion is further confirmed, when we compare the quantity of land lying between the poles and the 30th parallels of north and south latitude, and the quantity placed between those parallels and the equator ; for, it is clear, that at present we must have not only more than the usual degree of cold in the polar regions, but also less than the average quantity of heat generated in the intertropical zone.

Position of land and sea which might produce the extreme of cold of which the earth's surface is susceptible.

— In order to simplify our view of the various changes in climate, which different combinations of geographical circumstances may produce, we shall first consider the conditions necessary for bringing about the extreme of cold, or what may be termed the winter of the “ great year,” or geological cycle, and afterwards, the conditions requisite for producing the maximum of heat, or the summer of the same year.

To begin with the northern hemisphere. ~~Let~~ us suppose those hills of the Italian peninsula and of Sicily, which are of comparatively modern origin, and contain many fossil shells identical with living species, to subside again into the sea, from which they have been raised, and that an extent of land of equal area and height (varying from one to three thousand feet) should rise up in the Arctic ocean between Siberia and the north pole. In speaking of such changes, I need not allude to the manner in which I conceive it

niveau, hauteur qui ne surpasse pas mille mètres (3280 ft.).” *Mec. Céleste*, Bk. xi. et *Syst. du Monde*, p. 254.

possible that they may be brought about, nor of the time required for their accomplishment,—reserving for a future occasion, not only the proofs that revolutions of equal magnitude have taken place, but that analogous mutations are still in gradual progress. The alteration now supposed in the physical geography of the northern regions would cause additional snow and ice to accumulate where now there is usually an open sea; and the temperature of the greater part of Europe would be somewhat lowered, so as to resemble more nearly that of corresponding latitudes of North America: or, in other words, it might be necessary to travel about 10° farther south in order to meet with the same climate which we now enjoy. There would be no compensation derived from the disappearance of land in the Mediterranean countries; for, on the contrary, the mean heat of the soil so situated, is probably far above that which would belong to the sea, by which we imagine it to be replaced.

But let the configuration of the surface be still further varied, and let some large district within or near the tropics, such as Mexico, for example, with its mountains rising to the height of twelve thousand feet and upwards, be converted into sea, while lands of equal elevation and extent are transferred to the arctic circle. From this change there would, in the first place, result a sensible diminution of temperature near the tropic, for the soil of Mexico would no longer be heated by the sun; so that the atmosphere would be less warm, as also the neighbouring Atlantic, and Gulf stream. On the other hand, the whole of Europe, Northern Asia, and North America, would feel the influence of the enormous quantity of ice and snow, thus generated at vast heights on the new

arctic continent. If, as we have already seen, there are now some points in the southern hemisphere where snow is perpetual to the level of the sea, in latitudes as low as central England, such might assuredly be the case throughout a great part of Europe, under the change of circumstances above supposed; and if at present the extreme limits of drifted icebergs are the Azores, they might easily reach the equator after the alteration before alluded to. To pursue the subject still farther, let the Himalaya mountains, with the whole of Hindostan, sink down, and their place be occupied by the Indian ocean, and then let an equal extent of territory and mountains, of the same vast height, stretch from North Greenland to the Orkney islands. It seems difficult to exaggerate the amount to which the climate of the northern hemisphere would now be cooled down.

But, notwithstanding the great refrigeration which would thus be produced, it is probable that the difference of mean temperature between the arctic and equatorial latitudes would not be increased in a very high ratio; for no great disturbance can be brought about in the climate of a particular region, without immediately affecting all other latitudes, however remote. The heat and cold which surround the globe are in a state of constant and universal flux and reflux. The heated and rarefied air is always rising and flowing from the equator towards the poles in the higher regions of the atmosphere; and, in the lower, the colder air is flowing back to restore the equilibrium. That this circulation is constantly going on in the aërial currents is not disputed; it is often proved by the opposite direction of the course of the clouds at different heights, and the fact was farther illustrated

in a striking manner by an event which happened in the present century. The trade wind continually blows with great force from the island of Barbadoes to that of St. Vincent's; notwithstanding which, during the eruption of the volcano in the island of St. Vincent, in 1812, ashes fell in profusion from a great height in the atmosphere upon Barbadoes. This apparent transportation of matter against the wind, confirmed the opinion of the existence of a counter-current in the higher regions, which had previously rested on theoretical conclusions.*

That a corresponding interchange takes place in the seas, is demonstrated, according to Humboldt, by the cold which is found to exist at great depths between the tropics; and, among other proofs, may be mentioned the great volume of water which the Gulf stream is constantly bearing northwards, while another current flows *from* the north along the coast of Greenland and Labrador, and helps to restore the equilibrium.†

Currents of heavier and colder water pass from the poles towards the equator, which cool the inferior parts of the ocean‡; so that the heat of the torrid zone and the cold of the polar circle balance each other. The refrigeration, therefore, of the polar regions, resulting from the supposed alteration in the

* Daniell's Meteorological Essays, &c. p. 103.

† In speaking of the circulation of air and water in this chapter, no allusion is made to the trade winds, or to irregularities in the direction of currents, caused by the rotatory motion of the earth. These causes prevent the movements from being direct from north to south, or from south to north, but they do not affect the theory of a constant circulation.

‡ See note, p. 160., on the increasing density of sea-water in proportion to the degree of cold.

distribution of land and sea, would be immediately communicated to the tropics, and from them would extend to the antarctic circle, where the atmosphere and the ocean would be cooled, so that ice and snow would augment. Although the mean temperature of higher latitudes in the southern hemisphere is, as before stated, for the most part lower than that of the same parallels in the northern, yet, for a considerable space on each side of the line, the mean annual heat of the waters is found to be the same in corresponding parallels. When, therefore, by the new position of the land, the generating of icebergs had become of common occurrence in the northern temperate zone, and when they were frequently drifted as far as the equator, the same degree of cold would immediately be communicated as far as the tropic of Capricorn, and from thence to the lands or ocean to the south.

The freedom, then, of the circulation of heat and cold from pole to pole being duly considered, it will be evident that the mean quantity of solar heat which may visit the same point at two distinct periods, may differ far more widely than the mean quantity which any two points receive in the same parallels of latitude, at one and the same period. For the range of temperature in a given zone, or, in other words, the curves of the isothermal lines, must always be circumscribed within narrow limits, the climate of each place in that zone being controlled by the combined influence of the geographical peculiarities of all other parts of the earth. Whereas, if we compare the state of things as existing at two distinct epochs, a particular zone may at one time be under the influence of one class of disturbing causes, as under those of a refrigerating nature, and at another time may be affected by a

combination of opposite circumstances. The lands, for example, to the north of Greenland cause the present climate of North America to be colder than that of Europe in the same latitudes; but the excess of cold is not so great, as would have been the case, if the western hemisphere had been entirely isolated, or separated from the eastern like a distinct planet. For not only does the refrigeration produced by Greenland chill to a certain extent the atmosphere of northern and western Europe, but the mild climate of Europe reacts also upon North America, and moderates the chilling influence of the adjoining polar lands.

To return to the state of the earth after the changes before supposed, we must not omit to dwell on the important effects to which a wide expanse of perpetual snow would give rise. It is probable that nearly the whole sea, from the poles to the parallels of 45° , would be frozen over; for it is well known that the immediate proximity of land is not essential to the formation and increase of field ice, provided there be in some part of the same zone a sufficient quantity of glaciers generated on or near the land, to cool the sea. Captain Scoresby, in his account of the arctic regions, observes, that when the sun's rays "fall upon the snow-clad surface of the ice or land, they are in a great measure reflected, without producing any material elevation of temperature; but when they impinge on the black exterior of a ship, the pitch on one side occasionally becomes fluid, while ice is rapidly generated at the other."*

Now field ice is almost always covered with snow †; and thus not only land as extensive as our existing con-

* See Scoresby's Arctic Regions, vol. i. p. 378. † Ib. p. 320.

tinents, but immense tracts of sea in the frigid and temperate zones, might present a solid surface covered with snow, and reflecting the sun's rays for the greater part of the year. Within the tropics, moreover, where the ocean is supposed to predominate, the sky would no longer be serene and clear, as in the present era; but the melting of floating ice would cause quick condensations of vapour, and fogs and clouds would deprive the vertical rays of the sun of half their power. The whole planet, therefore, would receive annually a smaller proportion of solar influence, and the external crust would part, by radiation, with some of the heat which had been accumulated in it, during a different state of the surface. This heat would be dissipated into the spaces surrounding our atmosphere, which, according to the calculations of M. Fourier, have a temperature much inferior to that of freezing water.

After the geographical revolution above assumed, the climate of equinoctial lands might resemble that of the present temperate zone, or perhaps be far more wintery. They who should then inhabit such small isles and coral reefs as are now seen in the Indian ocean and South Pacific, would wonder that zoophytes of such large dimensions had once been so prolific in those seas; or if, perchance, they found the wood and fruit of the cocoa-nut tree or the palm silicified by the waters of some ancient mineral spring, or incrustated with calcareous matter, they would muse on the revolutions that had annihilated such genera, and replaced them by the oak, the chestnut, and the pine. With equal admiration would they compare the skeletons of their small lizards with the bones of fossil alligators and crocodiles more than twenty feet in length, which, at a former epoch, had multiplied between the tropics:

and when they saw a pine included in an iceberg, drifted from latitudes which we now call temperate, they would be astonished at the proof thus afforded, that forests had once grown where nothing could be seen in their own times but a wilderness of snow.

If the reader hesitate to suppose so extensive an alteration of temperature as the probable consequence of geographical changes, confined to one hemisphere, he should remember how great are the local anomalies in climate now resulting from the peculiar distribution of land and sea in certain regions. Thus, in the island of South Georgia, before mentioned, Captain Cook found the everlasting snows descending to the level of the sea, between lat. 54° and 55° S.; no trees or shrubs were to be seen, and a few rocks only, after a partial melting of the ice and snow in summer, were scantily covered with moss and tufts of grass. If such a climate can now exist at the level of the sea in a latitude corresponding to that of Yorkshire, in spite of those equalizing causes before enumerated, by which the mixture of the temperatures of distant regions is facilitated throughout the globe, what rigours may we not anticipate in a winter generated by the transfer of the mountains of India to our arctic circle!

But we have still to contemplate the additional refrigeration which other changes in the relative position of land and sea in the southern hemisphere might effect. If the remaining continents were transferred from the equatorial and contiguous latitudes to the south polar regions, the intensity of cold produced might, perhaps, render the globe uninhabitable. We are too ignorant of the laws governing the direction of subterranean forces, to determine whether such a crisis be within the limits of possibility. At the same time,

it may be observed, that no distribution of land can well be imagined more irregular, or, as it were, capricious, than that now prevailing; for at present, by drawing a line in a particular direction, the globe may be divided into two equal parts, in such a manner, that one hemisphere shall be entirely covered with water with the exception of some promontories and islands while the other shall contain less water than land; and what is still more extraordinary, on comparing the extratropical lands in the northern and southern hemispheres, the lands in the northern are found to be to those in the southern in the proportion of thirteen to one! * To imagine all the lands, therefore, in high and all the sea in low latitudes, as delineated in the annexed plate, would scarcely be a more anomalous state of the surface.

Position of land and sea which might give rise to the extreme of heat.—Let us now turn from the contemplation of the winter of the “great year,” and consider the opposite train of circumstances which would bring on the spring and summer. That some part of the vast ocean which forms the Atlantic and Pacific should, at certain periods, entirely occupy one or both of the polar regions, and should extend, interspersed with islands only, to the parallels of 40° and even 30° , is an event that may be supposed in the highest degree probable, in the course of many great geological revolutions. In order to estimate the degree to which the general temperature would then be elevated, we should begin by considering separately the effect of the diminution of certain portions of land in high northern latitudes, which might cause the sea

* Humboldt on Isothermal Lines.

to be as open in every direction as it is at present towards the north pole, in the meridian of Spitzbergen. By transferring the same lands to the torrid zone, we might gain farther accessions of heat, and cause the ice towards the south pole to diminish. We might first continue these geographical mutations, until we had produced as mild a climate in high latitudes as exists at those points in the same parallel where the mean annual heat is now greatest. We should then endeavour to calculate what further alterations would be required to double the amount of change; and the great deviation of isothermal lines at present seems to authorize us to infer, that without an entire revolution of the surface, we might cause the mean temperature to vary to an extent equivalent to 20° or even 30° of latitude, — in other words, we might transfer the temperature of the torrid zone to the mean parallel, and of the latter, to the arctic regions. By additional transpositions, therefore, of land and sea, we might bring about a still greater variation, so that, throughout the year, all signs of frost should disappear from the earth.

The plane of congelation would rise in the atmosphere in all latitudes; and as our hypothesis would place all the highest mountains in the torrid zone, they would be clothed with rich vegetation to their summits. We must recollect that even now it is necessary to ascend to the height of fifteen thousand feet in the Andes under the line, and in the Himalaya mountains, which are without the tropic, to seventeen thousand feet, before we reach the limit of perpetual snow. On the northern slope, indeed, of the Himalaya range, where the heat radiated from a great continent moderates the cold, there are meadows and cultivated land at an ele-

vation equal to the height of Mont Blanc.* When the absorption of the solar rays was unimpeded, even in winter, by a coat of snow, the mean heat of the earth's crust would augment to considerable depths, and springs, which we know to be an index of the mean temperature of the climate, would be warmer in all latitudes. The waters of lakes, therefore, and rivers, would be much hotter in winter, and would be never chilled in summer by the melting of snow. A remarkable uniformity of climate would prevail amid the numerous archipelagos of the polar ocean, amongst which the tepid waters of equatorial currents would freely circulate. The general humidity of the atmosphere would far exceed that of the present period, for increased heat would promote evaporation in all parts of the globe. The winds would be first heated in their passage over the tropical plains, and would then gather moisture from the surface of the deep, till, charged with vapour, they would arrive at extreme northern and southern regions, and there encountering a cooler atmosphere, would discharge their burden in warm rain. If, during the long night of a polar winter, the snows should whiten the summit of some arctic islands, and ice collect in the bays of the remotest Thule, they would be dissolved as rapidly by the returning sun, as are the snows of Etna by the blasts of the sirocco.

We learn from those who have studied the geographical distribution of plants, that in very low latitudes, at present, the vegetation of small islands remote from continents has a peculiar character; and the ferns and allied families, in particular, bear a great proportion to the total number of other vegetables. Other

* Humboldt, *Tableaux de la Nature*, tom. i. p. 112.

circumstances being the same, the more remote the isles are from the continents, the greater does this proportion become. Thus, in the continent of India, and the tropical parts of New Holland, the proportion of ferns to the phanerogamic plants is only as one to twenty-six; whereas, in the South-Sea Islands, it is as one to four, or even as one to three.* We might expect, therefore, in the summer of the "great year," which we are now considering, that there would be a predominance of tree-ferns and plants allied to palms and arborescent grasses in the isles of the wide ocean, while the dicotyledonous plants and other forms now most common in temperate regions would almost disappear from the earth. Then might those genera of animals return, of which the memorials are preserved in the ancient rocks of our continents. The huge *iguanodon* might reappear in the woods, and the *ichthyosaurus* in the sea, while the *pterodactyle* might flit again through umbrageous groves of tree-ferns. Then might coral reefs be prolonged once more beyond the arctic circle, where the whale and the narwal now abound; and turtles might again deposit their eggs in the sand of the sea-beach, where now the walrus sleeps, and where the seal is drifted along on floating fields of ice.

But, not to indulge these speculations farther, I may observe, in conclusion, that however great, in the lapse of ages, may be the vicissitudes of temperature in every zone, it accords with this theory that the general climate should not experience any sensible change in the course of a few thousand years; because that period is insufficient to affect the leading features of the phy-

* Ad. Brongniart, *Consid. Générales sur la Nat. de la Végét.* &c. *Ann. des Sciences Nat.* Nov. 1828.

sical geography of the globe. Notwithstanding the apparent uncertainty of the seasons, it is found that the mean temperature of particular localities is very constant, provided we compare observations made at different periods for a series of years.

Yet, there must be exceptions to this rule, and even the labours of man have, by the drainage of lakes and marshes, and the felling of extensive forests, caused such changes in the atmosphere as greatly to raise our conception of the more important influence of those forces to which even the existence, in certain latitudes, of land or water, hill or valley, lake or sea, must be ascribed. If we possessed accurate information of the amount of *local* fluctuation in climate in the course of twenty centuries, it would often, undoubtedly, be considerable. Certain tracts, for example, on the coast of Holland and of England consisted of cultivated land in the time of the Romans, which the sea, by gradual encroachments, has at length occupied. Here, at least, a slight alteration has been effected; for neither the division of heat in the different seasons, nor the mean annual heat of the atmosphere investing the sea, is precisely the same as that which rests on the land.

In those countries, also, where the earthquake and volcano are in full activity, a much shorter period may produce a sensible variation. The climate of the once fertile plain of Malpais in Mexico must differ materially from that which prevailed before the middle of the last century; for, since that time, six mountains, the highest of them rising sixteen hundred feet above the plateau, have been thrown up by volcanic eruptions. It is by the repetition of an indefinite number of local revolutions due to volcanic and various other causes, that a general change of climate may finally be brought about.

CHAPTER VIII.

**FURTHER EXAMINATION OF THE QUESTION AS TO THE
DISCORDANCE OF THE ANCIENT AND MODERN CAUSES
OF CHANGE.**

That the geographical features of the northern hemisphere, at the period of the deposition of the carboniferous strata, were such as might, according to the theory before explained, have given rise to an extremely hot climate — State of the surface when the transition and mountain limestones, coal-sandstones, and coal originated — Successive changes in the physical geography of northern latitudes, between the era of the formation of the carboniferous series and the chalk — Character of organic remains during these periods — Abrupt transition from the organic remains of the secondary to those of the tertiary strata — Maestricht beds — Great accession of land, and elevation of mountain chains, after the consolidation of the newer secondary rocks — Consequent refrigeration of climate — Remarks on the theory of the diminution of central heat — Astronomical causes of fluctuations in climate.

That the geographical features of the northern hemisphere, at the period of the deposition of the carboniferous strata, were such as might have given rise to an extremely hot climate. — In the sixth chapter, I stated many reasons for concluding that the mean annual temperature of the northern hemisphere was considerably more elevated when the old carboniferous strata were deposited; as also that the climate had been modified more than once since that epoch, and that it approximated by successive changes more and more nearly to that now prevailing in the same latitudes. Further, I en-

deavoured, in the last chapter, to prove that vicissitudes in climate of no less importance may be expected to recur in future, if it be admitted that causes now active in nature have power, in the lapse of ages, to produce considerable variations in the relative position of land and sea. It remains to inquire whether the alterations, which the geologist can prove to have actually taken place at former periods, in the geographical features of the northern hemisphere, coincide in their nature, and in the time of their occurrence, with such revolutions in climate as would naturally have followed, according to the meteorological principles already explained.

The great carboniferous series, including the transition and mountain limestones, and the coal, may be selected as the oldest system of rocks of which the organic remains furnish any decisive evidence as to climate. The indications which they afford of great heat and uniformity of temperature extend, as was before mentioned, over a vast area, from about 45° to 60° , or, perhaps, if we include Melville Island, to near 75° north latitude.*

When we attempt to restore in imagination the distribution of land and sea, as they existed at that remote epoch, we discover that our information is at pre-

* Our ancient coal-formation has not been found in Italy, Spain, Sicily, or any of the more southern countries of Europe. Whether any of the ammonitiferous limestones of the Southern Apennines and Sicily (Taormina for example) can be considered as of contemporaneous origin with our carboniferous series, is not yet determined; but it is conjectured, from the general character of the organic remains of the Apennine limestones, that they belong to some part of our secondary series, from the lias to the chalk inclusive.

sent limited to latitudes north of the tropic of Cancer ; and we can only hope, therefore, to point out that the condition of the earth, so far as relates to our temperate and arctic zones, was such as the theory before offered would have led us to anticipate. Now there is scarcely any land hitherto examined in Europe, Northern Asia, or North America, which has not been raised from the bosom of the deep since the origin of the carboniferous rocks, or which, if previously raised, has not subsequently acquired additional altitude. If we were to submerge again all the marine strata, from the transition limestone to the most recent shelly beds, the summits of some primary mountains alone would remain above the waters. These facts, it is true, considered singly, are not conclusive as to the universality of the ancient ocean in the northern hemisphere ; because the movements of earthquakes occasion the subsidence as well as the upraising of the surface, and by the alternate rising and sinking of particular spaces, at successive periods, a great area may become entirely covered with marine deposits, although the whole has never been beneath the waters at one time, nay, even though the relative proportion of land and sea may have continued unaltered throughout the whole period.

There is, however, the highest presumption against such an hypothesis, because the land in the northern hemisphere is now in great excess ; and this circumstance alone should induce us to suppose that, amid the repeated changes which the surface has undergone, the sea has usually predominated in a much greater degree. But when we study the mineral composition and fossil contents of the older strata, we find evidence

of a more positive and unequivocal kind in confirmation of the same opinion.

State of the surface when the transition and mountain limestones, coal-sandstones, and coal originated. — Calcareous rocks, containing the same class of organic remains as our transition and mountain limestones, extend over great part of central and northern Europe, are found again in the lake district of North America, and even appear to occur in great abundance as far as the borders of the Arctic Sea.* The organic remains of these rocks consist principally of marine shells, corals, and the teeth and bones of fish; and their nature, as well as the continuity of the calcareous beds of homogeneous mineral composition, concur to prove that the whole series was formed in a deep and expansive ocean, in the midst of which, however, there were many isles. These isles were composed partly of hypogene (primary) and partly of volcanic rocks, which, being exposed to the erosive action of torrents, to the undermining power of the waves beating against the cliffs, and to atmospheric

* It appears from the observations of Dr. Richardson, made during the expedition under the command of Captain Franklin to the north-west coast of America, and from the specimens presented by him to the Geological Society of London, that, between the parallels of 60° and 70° north latitude, there is a great calcareous formation, stretching towards the mouth of the Mackenzie river, in which are included corallines, productæ, terebratulæ, &c. having a close affinity in generic character to those of our mountain limestone, of which the group has been considered the equivalent. There is also in the same region a newer series of strata, in which are shales with impressions of ferns, lepidodendrons, and other vegetables, and also ammonites. These, it is supposed, may belong to the age of our oolitic series. — *Proceedings of Geological Society, March, 1828.*

decomposition, supplied materials for pebbles, sand, and shale, which, together with substances introduced by mineral springs and volcanos in frequent eruption, contributed the inorganic parts of the carboniferous strata.

The disposition of the beds in that portion of this group which is of mechanical origin, and which incloses the coal, has been truly described to be such as would result from the waste of small islands placed in rows, and forming the highest points of ridges of submarine mountains. The disintegration of such clusters of isles would produce around and between them detached deposits of various dimensions, which, when subsequently raised above the waters, would resemble the strata formed in a chain of lakes. The insular masses of hypogene (or primary) rock would preserve their original relative superiority of height, and would often surround the newer strata on several sides, like the boundary heights of lake basins.*

As might have been expected, the zoophytic and shelly limestones of the same era (as the mountain limestone) sometimes alternate with the rocks of mechanical origin, but appear to have been, in ordinary cases, diffused far and wide over the bottom of the sea, remote from any islands, and where no grains of sand were transported by currents. The associated volcanic rocks resemble the products of submarine eruptions, the tuffs being sometimes interstratified with calcareous shelly beds, or with sandstones, just as might be expected if the sand and ejected matter of which they are probably composed had been intermixed with the

* See some ingenious remarks to this effect, in the work of M. Ad. Brongniart, *Consid. Générales sur la Nat. de la Végét. &c.* Ann. des Sci. Nat., Nov. 1828.

waters of the sea, and had then subsided like other sediment. The lavas also often extend in spreading sheets, and must have been poured out on a surface rendered horizontal by sedimentary depositions. There is, moreover, a compactness and general absence of porosity in these igneous rocks, which distinguishes them from most of those produced in the open air on the sides of Etna, Vesuvius, and other land volcanos.

If, on the other hand, we examine the fossil remains of these strata, we find the vegetation declared by botanists to possess the characters of an insular, not a continental flora; and we may suppose the carbonaceous matter to have been derived partly from trees swept from the rocks by torrents into the sea, and partly from such dark vegetable matter as often discolours and blackens the rills flowing through marshy grounds in our temperate climate, where the vegetation is probably less rank, and its decomposition less rapid, than in the moist and hot climate of the era under consideration.

There is, as yet, no well authenticated instance of the remains of a saurian animal having been found in a member of the carboniferous series.* The larger oviparous reptiles usually inhabit rivers of considerable size in warm latitudes; and had crocodiles and other

* It is, indeed, stated that, among other fossils collected from the mountain limestone of Northumberland, the Rev. Charles V. Vernon Harcourt has been fortunate enough

Unius sese dominum fecisse lacertæ ;

having found a saurian vertebra, together with patellæ and echinal spines, and an impression of a fern analogous to those of the coal measures in the mountain limestone. Annual Report of the Yorkshire Phil. Soc. for 1826, p. 14. But I am informed by Mr. Harcourt himself, that the vertebra was discovered in loose alluvium.

animals of that class been abundant in a fossil state, as in some of the newer secondary formations, we must have inferred the existence of many rivers, which could only have drained large tracts of land. Nor have the bones of any terrestrial mammalia rewarded our investigations. Had any of these, belonging to quadrupeds of large size, occurred, they would have supplied an argument against the resemblance of the ancient northern archipelagos to those of the modern Pacific; since in the latter no great indigenous quadrupeds have been met with.

It is, indeed, a general character of small islands situated at a remote distance from continents, to be altogether destitute of land quadrupeds, except such as appear to have been conveyed to them by man. Kerguelen's land, which is of no inconsiderable size, placed in lat. $49^{\circ} 20'$ S., a parallel corresponding to that of the Scilly islands, may be cited as an example, as may all the groups of fertile islands in the Pacific Ocean between the tropics, where no quadrupeds have been found, except the dog, the hog, and the rat, which have probably been brought to them by the natives, and also bats, which may have made their way along the chain of islands which extend from the shores of New Guinea far into the southern Pacific.* Even the isles of New Zealand, which may be compared to Ireland and Scotland in dimensions, appear to possess no indigenous quadrupeds, except the bat; and this is rendered the more striking, when we recollect that the northern extremity of New Zealand stretches to latitude 34° , where the warmth of the climate must greatly favour the prolific development of organic life

* Prichard's *Phys. Hist. of Man*, vol. i. p. 75.

Lastly, no instance has yet been discovered of a pure lacustrine formation of the carboniferous era ; although there are some instances of shells, apparently fresh-water, which may have been washed in by small streams, and do not necessarily imply a considerable extent of dry land.

All circumstances, therefore, point to one conclusion : —the subaqueous character of the igneous products — the continuity of the calcareous strata over vast spaces — the marine nature of their organic remains — the basin-shaped disposition of the mechanical rocks — the absence of large fluviatile and of land quadrupeds — the non-existence of pure lacustrine strata — the insular character of the flora, — all concur with wonderful harmony to establish the prevalence throughout the northern hemisphere of a great ocean, interspersed with small isles. If we seek for points of analogy to this state of things, we must either turn to the North Pacific, and its numerous submarine insular volcanos between Kamtschatka and New Guinea : or, in order to obtain a more perfect counterpart to the coralline and shelly limestones, we must explore the archipelagos of the South Pacific, between Australia and South America, where volcanos are not wanting, and where coral reefs, consisting in great part of compact limestone, are spread over an area not inferior, perhaps, to that of our ancient calcareous rocks, though we suppose these to be prolonged from the lakes of North America to central Europe.*

No geologists have ever denied, that when our oldest fossiliferous rocks were produced, great continents were wanting in the temperate and arctic zones

* See Book iii. On coral reefs.

north of the equator: on the contrary, they have been disposed to go too far, and to speculate on the universality of what they termed the primeval ocean. As well might the New Zealander, who had surveyed and measured the quantity of land between the south pole and the tropic of Capricorn, assume that the same proportion would be found to exist between the tropic of Cancer and the north pole. By this generalization, he would annihilate twelve out of thirteen parts of the land of our temperate and arctic zones. It would, however, be rash to infer, from any geological data hitherto obtained, that the ocean was ever universal; or, in other words, that the superficial crust of the earth was once more even than at present. It is merely probable, that the ocean was at certain periods in excess in high latitudes when the land predominated within the tropics, where, being exposed to the direct rays of the sun, it may have heated the winds and currents which flowed from lower to higher latitudes, and thus have produced an elevated temperature.

Changes in the physical geography of northern latitudes, after the formation of the carboniferous series. —

We have evidence in England, that the strata of the ancient carboniferous group, already adverted to, were fractured and contorted, and often thrown into vertical positions before the origin of some of the newer secondary rocks, such as the new red sandstone.

Fragments of the older formations are sometimes included in the conglomerates of the more modern; and some of these fragments still retain their fossil shells and corals, so as to enable us to determine the parent rocks from whence they were derived.* There are

* Thus, for example, on the banks of the Avon, in the Bristol

other proofs of the disturbance at successive epochs of different secondary rocks before the deposition of others ; and satisfactory evidence that, during these reiterated convulsions, the geographical features of the northern hemisphere were frequently modified, and that from time to time new lands emerged from the deep. The vegetation during some parts of the period in question, (from the lias to the chalk inclusive,) appears to have approached to that of the larger islands of the equatorial zone ; such, for example, as we now find in the West Indian archipelago.* These islands appear to have been drained by rivers of considerable size, which were inhabited by crocodiles and gigantic oviparous reptiles, both herbivorous and carnivorous, belonging for the most part to extinct genera. Of the contemporary inhabitants of the land we have as yet acquired but scanty information, but we know that there were flying reptiles, insects, and small mammifera, allied to the opossum.

Before the close, indeed, of the great “ secondary ” period above alluded to, it appears more than probable, that a vast continent approached very near to the space now occupied by the south-eastern parts of

coal-field, the dolomitic conglomerate, a rock of an age intermediate between the carboniferous series and the lias, rests on the truncated edges of the coal and mountain limestone, and contains rolled and angular fragments of the latter, in which are seen the characteristic mountain-limestone fossils. For accurate sections illustrating the disturbances which rocks of the carboniferous series underwent before the newer red sandstone was formed, the reader should consult the admirable memoir on the south-western coal district of England, by Dr. Buckland and Mr. Conybeare, *Geol. Trans.* vol. i. second series.

* Ad. Brongniart, *Consid. Générales sur la Nat. de la Végét.* &c. *Ann. des Sci. Nat.*, Nov. 1828.

England. For the Wealden beds, which underlie the chalk, imply the continual influx into the sea of a large river, equal in size to the Ganges or the Indus.*

It might at first appear, that the position of a continent so far to the north, at a time when the mean temperature of the climate is supposed to have been much hotter than at present, is inconsistent with the theory before explained, that the heat was caused by the gathering together of all the great masses of land in low latitudes, while the polar regions were almost entirely sea. But provided that none of the land was arctic or antarctic, and a large part of the continents intra-tropical, considerable elevation of temperature may be presumed to result, even when large continental tracts were prolonged from the equatorial to the temperate zone.

It will be seen, in the fourth book, (chap. xxiii.) that the Maestricht beds are classed as the newest of the secondary series; and the fossils of that group, including the remains of gigantic reptiles, indicate the prevalence of a very hot climate. Between this uppermost member of the secondary series, and the oldest of the newer class of formations called tertiary, there is a remarkable discordance as to *species* of organic remains, none having yet been found common to both. This abrupt transition from one set of fossils to another, is also accompanied by evident signs of a change of climate; the Eocene tertiary species having a far less tropical aspect than those found fossil in the newest secondary group.

Now there is a decided coincidence between this alteration of climate, and geographical changes which

* Book iv. chap. xxiii.

occurred between the formation of the cretaceous series and that of the older tertiary group.* There may also be traced, on comparing the tertiary groups of different ages, a gradual approximation in the imbedded fossils from an assemblage in which extinct species predominate, to one where the species agree for the most part with those now existing. In other words, we find a gradual increase of animals and plants fitted for our present climates, in proportion as the strata which we examine are more modern. Now, during all these successive tertiary periods, there are signs of a great increase of land in European latitudes, which may perhaps have been compensated by the disappearance of continents nearer the line. By reference to the map, and its description given at the end of this chapter, the reader will see how great has been the physical revolutions which have occurred in Europe since the commencement of the tertiary period. The chalk, and several associated groups, are of considerable extent, and sometimes rise to the summits of lofty mountains. As these groups contain almost exclusively marine remains, it follows that every tract which they now occupy has, since their origin, been converted from sea into land, and, in some cases, from deep sea to mountains of great altitude. We cannot doubt that part of the mutations alluded to happened before the Eocene strata originated; because these last consist, in a great degree, of the ruins of the newer secondary rocks; which must therefore have been raised and exposed to aqueous erosion before the derivative beds were formed. It will moreover be seen, in the fourth book,

* See Chaps. xxi. and xxii. B. iv. on the period of the elevation of the chalk of the S. E. of England.

chap. iii., that the secondary and tertiary formations, considered generally, may be contrasted as having very different characters; the one appearing to have been deposited in open seas, the other in regions where dry land, lakes, bays, and perhaps inland seas, abounded. The secondary series is almost exclusively marine; the tertiary, even the oldest part, contains lacustrine strata, and not unfrequently freshwater and marine beds alternating. In many places, the former boundary of the tertiary sea may still be traced, and the line of its ancient cliffs and shores defined.

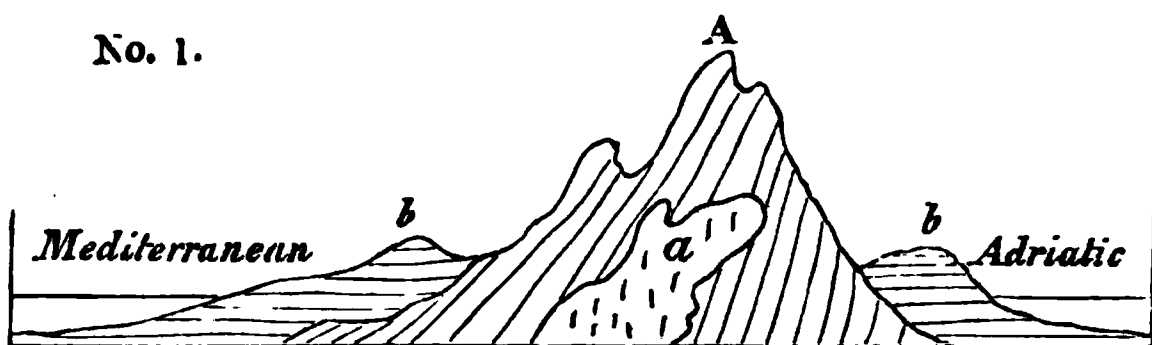
The facts depicted in the map (p. 209.) demonstrate that about two thirds of the present European lands have emerged since the earliest of these tertiary groups originated; nor is this the only change which the same region has undergone within a period comparatively so modern. Some of those tracts even which were previously land, have gained in altitude, or, on the contrary, have sunk below their former level, within the same period.

The evidence that the rise of land, above alluded to, did not take place all at the same time, is most striking. Several Italian geologists, even before the time of Brocchi, had justly inferred that the Apennines rose several thousand feet above the level of the Mediterranean, before the deposition of the recent Subapennine beds which flank them on either side. What now constitutes the central calcareous chain of the Apennines must for a long time have been a narrow ridgy peninsula, branching off, at its northern extremity, from the Alps near Savona. This peninsula was afterwards raised from one to two thousand feet, by which movement the ancient shores, and, for a certain extent, the

bed of the contiguous sea, were laid dry, both on the side of the Mediterranean, and the Adriatic.

The evidence of these vicissitudes will be explained by the accompanying diagram, which represents a

No. 1.



transverse section across the Italian peninsula. The inclined strata *A* are the disturbed formations of the Apennines into which the ancient igneous rocks *a* have intruded themselves. At a lower level on the flanks of the chain on each side are the more recent shelly beds *b b*, which often contain rounded pebbles derived from the waste of contiguous parts of the older Apennine limestone. These, it will be seen, are horizontal, and lie in what is termed “unconformable stratification” on the more ancient series. They now constitute a line of hills of moderate elevation between the sea and the Apennines, but never penetrating to the higher and more ancient valleys of that chain.

These phenomena are exhibited in the Alps on a much grander scale; those mountains being composed in some of their higher regions of newer secondary formations, while they are encircled by a great zone of tertiary rocks of different ages, both on their southern flank towards the plains of the Po, and on the side of Switzerland and Austria, and at their eastern termination towards Styria and Hungary.* This tertiary zone

* See a Memoir by Professor Sedgwick and Mr. Murchison, on the Alps. Trans. of Geol. Soc. second ser. vol. iii. part 2., accompanied by a map.

marks the position of former seas or gulfs, like the Adriatic, which were many thousand feet deep, and wherein strata accumulated; some single groups of which seem scarcely inferior in thickness to the whole of our secondary formations in England. These marine tertiary strata rise from the height of from two to four thousand feet and upwards, and consist of formations of different ages, characterized by different assemblages of organized fossils. The older tertiary groups generally rise to greater heights, and form interior zones nearest to the Alps. We may imagine some future convulsion once more to upraise this stupendous chain, together with the adjoining bed of the sea, so that the greatest mountains of Europe might then rival the Andes in elevation, in which case the deltas of the Po, Adige, and Brenta, now encroaching upon the Adriatic, might be uplifted so as to form another exterior belt of considerable height around the south-eastern flank of the Alps. Although we have not yet ascertained the number of different periods at which the Alps gained accessions to their height and width, yet we can affirm, that the last series of movements occurred when the seas were inhabited by many existing species of animals.

The Pyrenees, also, have acquired the whole of their present altitude, which in Mont Perdu exceeds eleven thousand feet, since the origin of some of the newer members of our secondary series. The granitic axis of that chain only attains about the same height as a ridge formed by marine calcareous beds, the organic remains of which show them to be the equivalents of our chalk and green-sand series.* The tertiary strata

* This observation, first made by M. Boué, has been since confirmed by M. Dufrénoy.

at the base of the chain are only raised to the height of a few hundred feet above the sea, and retain a horizontal position, without partaking in general in the disturbances to which the older series has been subjected; so that the great barrier between France and Spain was almost entirely upheaved in the interval between the deposition of the chalk and certain tertiary strata. The Jura, also, owe a great part of their present elevation to subterranean convulsions which happened after the deposition of certain tertiary groups.*

The remarkable break above alluded to, between the most modern of the known secondary rocks and the oldest tertiary, may be in some measure apparent only, and ascribable to the present deficiency of our information†; in which case the signs of intermediate gradations, by which a passage was effected from one state of things to another, may hereafter be discovered. Nevertheless, it is far from impossible that the interval between the chalk and tertiary formations constituted an era in the earth's history, when the transition from one class of organic beings to another was, comparatively speaking, rapid. For if the doctrines above explained in regard to vicissitudes of temperature are sound, it will follow that changes of equal magnitude in the geographical features of the globe, may at different periods produce very unequal effects on climate; and, so far as the existence of certain animals and plants depends on climate, the duration of species may often be shortened or protracted, according to the rate at which the change of temperature proceeded.

Let us suppose that the laws which regulate the

* M. Elie de Beaumont, *Ann. des Sci. Nat.*, Dec. 1829, p. 346.

† See Book iv. chap. 23.

subterranean forces are constant and uniform, (which we are entitled to assume, until some convincing proofs can be adduced to the contrary,) we may then infer, that a given amount of alteration in the superficial inequalities of the surface of the planet always requires for its consummation nearly equal periods of time. Let us then imagine the quantity of land between the equator and the tropic in one hemisphere to be to that in the other as thirteen to one, which, as we before stated, represents the unequal proportion of the extra-tropical lands in the two hemispheres at present. Then let the first geographical change consist in the shifting of this preponderance of land from one side of the line to the other, from the southern hemisphere, for example, to the northern. Now this need not affect the *general* temperature of the earth. But if, at another epoch, we suppose a continuance of the same agency to transfer an equal volume of land from the torrid zone to the temperate and arctic regions of the northern and southern hemisphere, or into one of them, there might be so great a refrigeration of the mean temperature *in all latitudes*, that scarcely any of the pre-existing races of animals would survive, and, unless it pleased the Author of Nature that the planet should be uninhabited, new species would then be substituted in the room of the extinct. We ought not, therefore, to infer, that equal periods of time are always attended by an equal amount of change in organic life, since a great fluctuation in the mean temperature of the earth, the most influential cause which can be conceived in exterminating whole races of animals and plants, must, in different epochs, require unequal portions of time for its completion.

For some additional facts and views respecting

revolutions in physical geography, of comparatively modern date, I refer the reader again to the description of the map appended to this chapter; and, in conclusion, shall merely affirm, that there is a marked coincidence between the eras of the principal alteration in climate, and the most extensive changes in the former position of the sea and land, so far as they are yet known to us. We have already seen, that the temperature was most elevated when the northern hemisphere seems to have been occupied by the ocean, and that the refrigeration increased in proportion as that ocean became converted into land; nor was the maximum of cold produced until the lands had attained their full extension, and the mountain chains of Europe their actual height.

Count Sternberg, in his comments on this theory of climate*, has objected that there are no geological proofs of the prevalence at any former period of a temperature *lower* than that now enjoyed; whereas, if the causes above assigned were the true ones, it might reasonably have been expected that fossil remains would sometimes indicate colder as well as hotter climates than those now established. This objection, however, is of no great weight, because it is probable that the time required to bring about a transposition of the site of the continents from polar to equatorial regions, or the reverse, may be also sufficient to modify almost entirely the earth's crust; the aqueous and igneous agents having power to destroy and renovate in the course of ages the whole exterior of the planet, in the manner to be described in the sequel. If this be the case, it may easily happen that

* Allgemeine Literatur Zeitung, No. cxxxix. July, 1833.

the fossiliferous strata of certain regions of the globe, such as Europe and North America, may have reference to part only of a complete cycle of change in the temperature of the earth's surface. The climate now enjoyed may be assumed, for reasons already explained, to be very distant from the extreme of possible cold; and, on the other hand, we have no right to suppose, that the fossils of the carboniferous era represent the maximum of heat. Our retrospect, therefore, into the history of the past, may only carry us over a small portion of one revolution, during which refrigeration may have been constant, although not uniform; for, as before hinted, the ratio of cooling may have been sometimes accelerated, as in the interval between the cretaceous and Eocene periods. We have only, then, to imagine, that the strata hitherto examined originated when the quantity of equatorial land was always decreasing, and the land in regions nearer the poles augmenting, in height and area, in which case every fossil flora and fauna may indicate the passage from a summer to a winter temperature.

Theory of Central Heat.—The gradual diminution of the supposed central heat of the globe has been resorted to by many geologists as the principal cause of alterations of climate. The matter of our planet is imagined, according to the conjecture of Leibnitz, to have been originally in an intensely heated state, and to have been parting ever since with portions of its heat, at the same time that it has contracted its dimensions. There are, undoubtedly, some grounds for inferring, from recent observation and experiment, that the temperature of the earth increases as we descend from the surface to that slight depth to which man can penetrate; but there are no proofs of a secular

decrease of heat accompanied by contraction. On the contrary, La Place has shown, by reference to astronomical observations made in the time of Hipparchus, that in the last two thousand years there has been no sensible contraction of the globe by cooling; for had this been the case, even to an extremely small amount, the day would have been shortened, whereas its length has certainly not diminished during that period by $\frac{1}{360}$ th of a second. Baron Fourier, after making a curious series of experiments on the cooling of incandescent bodies, has endeavoured, by profound mathematical calculations, to prove that the actual distribution of heat in the earth's envelope is precisely that which would have taken place if the globe had been formed in a medium of a very high temperature, and had afterwards been constantly cooled.*

Now this conclusion is appealed to by many as corroborating the theory of secular refrigeration, although the phenomenon might probably be ascribed, with equal propriety, to the action of volcanic heat, which we know has, in former ages, shifted its points of chief development over every part of the earth's crust.

M. Cordier announces as the result of his experiments and observations on the temperature of the interior of the earth, that the heat increases rapidly with the depth; but the increase does not follow the same law over the whole earth, being twice or three times as much in one country as in another, and these differences not being in constant relation either with the latitudes

* See a Memoir on the Temperature of the Terrestrial Globe, and the Planetary Spaces, *Ann. de Chimie et Phys.* tom. xxvii. p. 136. Oct. 1824.

or longitudes of places.* All this is precisely what we should have expected to arise from variations in the intensity of volcanic heat, and from that change of position, which the principal theatres of volcanic action can be proved to have undergone.

But the advocates of the doctrine of central heat contend, that although no contraction can be demonstrated to have taken place within the historical period (the operation being slow and the time of observation limited), yet it is no less certain that heat is annually passing out by radiation from the interior of the globe into the planetary spaces, while, on the other hand, there is no assignable mode in which this heat can be again restored to the earth. Streams of incandescent lava rise up from unknown depths, flow out upon the surface, and before they consolidate emit much light and heat. In what manner does the igneous and luminous matter, thus withdrawn from our planet, return again from the celestial spaces; or, if lost, does it not imply a continual cooling of the central parts of the earth?

This argument may appear plausible, until we reflect how ignorant we are of the sources of volcanic heat, or indeed of the nature of light and heat in general. It is doubtless true, that light and heat are continually emanating from the earth; but, in the same manner, it may be said that they escape without intermission from the sun, and we know not whether there be any compensating causes which again restore them to that luminary. — It is a mystery, says Herschel, speaking of the sun, to conceive how so enormous a conflagra-

* See M. Cordier's *Memoir on the Temperature of the Interior of the Earth*, read to the Academy of Sciences, 4th June, 1827. — *Edin. New Phil. Journ.* No. viii. p. 273.

tion (if such it be) can be kept up. Every discovery in chemical science here leaves us completely at a loss, or rather seems to remove farther the prospect of probable explanation. May not, he adds, a continual current of electric matter be constantly circulating in the sun's immediate neighbourhood, or traversing the planetary spaces? &c. &c.*

Those geologists who advocate the doctrine of terrestrial refrigeration may fairly be asked whether their theory might not be applied as well, or even preferably, to the sun instead of to the earth; for while there seem to be no positive facts which render the assumption more arbitrary in the one case than in the other, there may be some advantages in supposing a secular diminution of solar influence. If the great luminary, when first created, were in a more heated state, it would have given out by radiation an excess of such light and heat as might have produced the required effect on the ancient climates: but who shall declare whether, if the central nucleus of the earth were highly ignited, it would supply the habitable surface with the kind of heat which may explain the forms of fossil plants and animals?

Astronomical causes of fluctuations in climate. — Sir John Herschel has lately inquired, whether there are any astronomical causes which may offer a possible explanation of the difference between the actual climates of the earth's surface, and those which formerly appear to have prevailed. He has entered upon this subject, he says, "impressed with the magnificence of that view of geological revolutions, which regards them rather as regular and necessary effects of great and general causes, than as resulting from a series of

* Treatise on Astronomy, § 337.

convulsions and catastrophes, regulated by no laws, and reducible to no fixed principles." Geometers, he adds, have demonstrated the absolute invariability of the mean distance of the earth from the sun; whence it would at first seem to follow, that the mean annual supply of light and heat derived from that luminary would be alike invariable: but a closer consideration of the subject will show, that this would not be a legitimate conclusion; but that, on the contrary, the *mean* amount of solar radiation is dependent on the excentricity of the earth's orbit, and therefore liable to variation.*

Now, the excentricity of the orbit is actually diminishing, and has been so for ages beyond the records of history. In consequence, the ellipse is in a state of approach to a circle, and the annual average of solar radiation is actually on the *decrease*. So far this is in accordance with geological evidence, which indicates a general refrigeration of climate; but the question remains, whether the amount of diminution which the excentricity may have ever undergone, can be supposed sufficient to account for any sensible refrigeration. The calculations necessary to determine this point, though practicable, have never yet been made, and would be extremely laborious; for they must embrace all the perturbations which the

* The theorem is thus stated: — "The excentricity of the orbit varying, the total quantity of heat received by the earth from the sun in one revolution is inversely proportional to the minor axis of the orbit. The major axis is invariable, and therefore, of course, the absolute length of the year: hence it follows that the mean annual average of heat will also be in the same inverse ratio of the minor axis." — Geol. Trans. second series, vol. iii. p. 295.

most influential planets, Venus, Mars, Jupiter, and Saturn, would cause in the earth's orbit, and in each other's movements round the sun.

The problem is also very complicated, inasmuch as it depends not merely on the ellipticity of the earth's orbit, but on the assumed temperature of the celestial spaces beyond the earth's atmosphere; a matter still open to discussion, and on which MM. Fourier and Herschel have arrived at very different opinions. But if, says Herschel, we suppose an extreme case, as if the earth's orbit should ever become as excentric as that of the planet Juno, or Pallas, a great change of climate might be conceived to result, the winter and summer temperatures being sometimes mitigated, and at others exaggerated, in the same latitudes.

It is much to be desired that the calculations alluded to were executed, as even if they should demonstrate, as is highly probable, that the mean amount of solar radiation can never be materially affected by irregularities in the earth's motion, it would still be satisfactory to ascertain the point. Such inquiries, however, can never supersede the necessity of investigating the inevitable consequences of the varying position of continents, shifted as we know them to have been during successive epochs from one part of the globe to the other. In order to appreciate more justly the adequacy of such causes in giving rise to variations in climate, the reader is invited to study the geological facts delineated in the accompanying map.

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EXPLANATION OF THE MAP,

Showing the extent of surface in Europe which has been covered by water since the deposition of the Eocene Tertiary strata. (Strata of the Paris and London Basins, &c.)

[Constructed chiefly from M. Amie Boué's Geological Map of Europe.]

THIS map will enable the reader to perceive at a glance the great extent of change in the physical geography of Europe, which can be proved to have taken place since some of the older tertiary strata were deposited. The most ancient part of the period to which the map refers cannot be deemed very remote, considered geologically; because the deposits of the Paris and London basins, of Auvergne, and many other districts belonging to the Eocene tertiary epoch, are newer than the greater part of the sedimentary rocks of which the crust of the globe is composed. The species, moreover, of marine and fresh-water testacea, of which the remains are found in these most ancient tertiary formations, are not entirely distinct from such as now live; a proportion of more than three in a hundred of the fossils having been identified with species now living.* Yet, notwithstanding the comparatively recent epoch to which the retrospect is carried, the variations in the distribution of land and sea depicted on the map form only a part of those which must have taken place during the period under consideration. Some approximation has merely been made to a correct estimate of the amount of *sea converted into land* in part of Europe best known to geologists, but we

* See Book iv. ch. 5.

cannot determine how much land has become sea during the same period; and there may have been repeated interchanges of land and water in the same places, mutations of which no account is taken in the map, and respecting the amount of which little accurate information can ever be obtained by geologists.

The proofs of submergence, during some part or other of the tertiary period, in all the districts distinguished by ruled lines, are of a most unequivocal character; for the area thus described is now covered by deposits containing the fossil remains of aquatic animals belonging to tertiary species. I have, indeed, extended the sea in two or three instances beyond these limits, because other geological data have been obtained for inferring the submergence of these tracts subsequently to the commencement of the deposition of the tertiary strata. Thus I shall explain, in the 4th Book*, my reasons for concluding that part of the chalk of England (the north and south downs, for example, together with the intervening secondary tracts,) continued beneath the sea until the Eocene tertiary beds had begun to accumulate.

It is possible also that a considerable part of Caernarvonshire might with propriety have been represented as sea, if our information respecting the geology of that county had been more full and accurate; for marine shells have been found in sand and gravel at the height of one thousand feet above the level of the sea, on the summit of Moel Tryfane, between Snowdon and the Menai Straits. The species are apparently recent, but certainly are newer than the Eocene period.†

* Ch. xxi. and xxii.

† J. Trimmer, Esq. Proceedings Geol. Soc. London, No. 22. 1831.

The introduction of a small bay where the river Ribble enters into the sea in Lancashire is warranted by a newly discovered deposit of tertiary shells covering an area of about thirty miles square in that region.*

A portion also of the primary district in Brittany is divided into islands, because it has been long known to be covered with patches of marine tertiary strata; and when I examined the disposition of these, in company with my friend, Captain S. E. Cook, R. N., in 1830, I was convinced that the sea must have covered much larger areas than are now occupied by these small and detached deposits.

The former connexion of the White Sea and the Gulf of Finland is proved by the fact that a broad band of tertiary strata extends throughout part of the intervening space. The channel, it is true, is represented as somewhat broader than the tract now occupied by the tertiary formation; because the latter is bordered on the north-west by a part of Finland, which is extremely low, and so thickly interspersed with lakes as to be nearly half covered with fresh water.

Certain portions of the north-western shores of Norway have been left blank, because the discovery by Von Buch, Brongniart, and others, of deposits of recent shells along the coast of Norway and Sweden, at several places and at various heights above the level of the sea, attest the comparatively recent date of the elevation of part of the gneiss and other primary rocks in that country, although we are unable as yet to determine how far the sea may have extended.

* See memoir by Mr. Murchison, *Proceedings of York Meeting*, 1831.

On the other hand, a considerable space of low land along the shores of the Gulf of Bothnia, in the Baltic, is represented as sea; because the growth of deltas on that coast, and the shallowing of the water known to have taken place during the historical era, leave no room for doubt that the extent of the gulf must have been greater at some time since the Eocene period.

The low granitic steppe, coloured red, to the north of the Black Sea, has not been represented as having been under water during the tertiary period, although, from the quantity of marine tertiary strata in the surrounding districts, it is far from improbable that it has recently emerged.

I was anxious, even in the title of this map, to guard the reader against the supposition that it was intended to represent the state of the physical geography of part of Europe at any one *point of time*. The difficulty, or rather the impossibility, of restoring the geography of the globe as it may have existed at any former period, especially a remote one, consists in this, that we can only point out where part of the sea has been turned into land, and are almost always unable to determine what land may have become sea. All maps, therefore, pretending to represent the geography of remote geological epochs must be ideal. The map under consideration is not a restoration of a former state of things, but a synoptical view of a certain amount of one kind of change (the conversion of sea into land) known to have been brought about within a given period. The alteration has been so complete, that not one of the species of organic beings which now inhabit the large space designated by ruled lines, beyond the borders of the existing seas, can have lived there

during other periods subsequent to the commencement of the tertiary era.

In the former part of this chapter I have stated, that the movements of earthquakes occasion the subsidence as well as the upraising of the surface; and that, by the alternate rising and sinking of particular spaces, at successive periods, a great area may have been entirely covered with marine deposits, although the whole may never have been beneath the waters at one time; nay, even though the relative proportion of land and sea may have continued unaltered throughout the whole period. I believe, however, that since the commencement of the tertiary period, the dry land in the northern hemisphere has been continually on the increase, not only because it is now greatly in excess beyond the average proportion which land generally bears to water on the globe, but because the comparison of the secondary and tertiary strata implies a passage throughout the space now occupied by Europe, from the condition of an ocean interspersed with islands to that of a large continent.*

But if it were possible to represent all the vicissitudes in the distribution of land and sea that have occurred during the tertiary period, and to exhibit not only the actual existence of land where there was once sea, but also the extent of surface now submerged which may once have been land, the map would still fail to express all the important revolutions in physical geography which have taken place within the epoch under consideration. For the oscillations of level, as was before stated, have not merely been such as to lift up the land from below the waters, but in some

* See Book iv. chap. iii.

cases to occasion a rise of several thousand feet above the sea. Thus the Alps have acquired an additional altitude of from 2000 to 4000 feet, and even in some places still more; and the Apennines owe a great part of their height (from 1000 to 2000 feet and upwards) to subterranean convulsions which have happened within the tertiary epoch.

On the other hand, some mountain chains may have been lowered during the same series of ages, in an equal degree, and shoals may have been converted into deep abysses.

In conclusion it may be observed, that the facts exhibited in this map bear not merely on the theory of climate above proposed, but serve also to illustrate the views explained in the third book respecting the migrations of animals and plants, and the gradual extinction of species.

CHAPTER IX.

FURTHER DISCUSSION OF THE QUESTION AS TO THE DISCORDANCE OF THE ANCIENT AND MODERN CAUSES OF CHANGE.

Theory of the progressive development of organic life — Evidence in its support inconclusive — Vertebrated animals, and plants of the most perfect organization in strata of very high antiquity — Differences between the organic remains of successive formations — Remarks on the comparatively modern origin of the human race — The popular doctrine of successive development not confirmed by the admission that man is of modern origin — Introduction of man, to what extent a change in the system.

Progressive development of organic life. — In the preceding chapters I have considered many of the most popular grounds of opposition to the doctrine, that all former changes of the organic and inorganic creation are referrible to one uninterrupted succession of physical events, governed by the laws now in operation.

As the principles of the science must always remain unsettled so long as no fixed opinions are entertained on this fundamental question, I shall proceed to examine other objections which have been urged against the assumption of the identity of the ancient and modern causes of change. A late distinguished writer has formally advanced some of the most popular of these objections. “It is impossible,” he affirms, “to defend the proposition, that the present order of things is the ancient and constant order of nature, only modified by existing laws — in those strata which are deep-

est, and which must, consequently, be supposed to be the earliest deposited, forms even of vegetable life are rare; shells and vegetable remains are found in the next order; the bones of fishes and oviparous reptiles exist in the following class; the remains of birds, with those of the same genera mentioned before, in the next order; those of quadrupeds of extinct species in a still more recent class; and it is only in the loose and slightly consolidated strata of gravel and sand, and which are usually called diluvian formations, that the remains of animals such as now people the globe are found, with others belonging to extinct species. But, in none of these formations, whether called secondary, tertiary, or diluvial, have the remains of man, or any of his works, been discovered; and whoever dwells upon this subject must be convinced, that the present order of things, and the comparatively recent existence of man as the master of the globe, is as certain as the destruction of a former and a different order, and the extinction of a number of living forms which have no types in being. In the oldest secondary strata there are no remains of such animals as now belong to the surface; and in the rocks, which may be regarded as more recently deposited, these remains occur but rarely, and with abundance of extinct species;—there seems, as it were, a gradual approach to the present system of things, and a succession of destructions and creations preparatory to the existence of man.”*

In the above passages, the author deduces two important conclusions from geological data: first, that in the successive groups of strata, from the oldest to the

* Sir H. Davy, *Consolations in Travel*, Dialogue III. “The Unknown.”

most recent, there is a progressive development of organic life, from the simplest to the most complicated forms ;—secondly, that man is of comparatively recent origin. It will be easy to show that the first of these propositions, though very generally received, is most questionable, and has but a slender foundation in fact. The second, on the contrary, is indisputable ; and it is important, therefore, to consider how far its admission is inconsistent with the doctrine, that the system of the natural world may have been uniform from the beginning, or rather from the era when the oldest rocks hitherto discovered were formed.

First, then, let us consider the geological proofs appealed to in support of the theory of the successive development of animal and vegetable life, and their progressive advancement to a more perfect state. No geologists who are in possession of all the data now established respecting fossil remains, will for a moment contend for the doctrine in all its detail, as laid down by the great chemist to whose opinions we have referred ; but naturalists, who are not unacquainted with recent discoveries, continue to defend it in a modified form. They say that, in the first period of the world, (by which they mean the earliest of which we have yet procured any memorials,) the vegetation consisted almost entirely of cryptogamic plants, while the animals which co-existed were almost entirely confined to zoophytes, testacea, and a few fish. Plants of a less simple structure succeeded in the next epoch, when oviparous reptiles began also to abound. Lastly, the terrestrial flora became most diversified and most perfect when the highest orders of animals, the mammifera and birds, were called into existence.

Now, in the first place, it may be observed, that many

naturalists are guilty of no small inconsistency in endeavouring to connect the phenomena of the earliest vegetation with a nascent condition of organic life, and at the same time to deduce, from the numerical predominance of certain types of form, the greater heat of the ancient climate. The arguments in favour of the latter conclusion are without any force, unless we can assume that the rules followed by the Author of Nature in the creation and distribution of organic beings were the same formerly as now; and that as certain families of animals and plants are now most abundant, or exclusively confined to regions where there is a certain temperature, a certain degree of humidity, a certain intensity of light, and other conditions, so also the same phenomena were exhibited at every former era.

If this postulate be denied, and the prevalence of particular families be declared to depend on a certain order of precedence in the introduction of different classes into the earth, and if it be maintained that the standard of organization was raised successively, we must then ascribe the numerical preponderance in the earlier ages of plants of simpler structure, *not to the heat*, but to those different laws which regulate organic life in newly-created worlds. If, according to the laws of progressive development, cryptogamic plants always flourish for ages before the dicotyledonous order can be established, then is the small proportion of the latter fully explained; for in this case, whatever may have been the mildness or severity of the climate, they could not make their appearance.

Before we can infer an elevated temperature in high latitudes, from the presence of arborescent Ferns, *Lycopodiaceæ*, and plants of other allied families, we must be

permitted to assume, that at all times, past, present, and future, a heated and moist atmosphere pervading the northern hemisphere has a tendency to produce in the vegetation a predominance of analogous types of form.

In the ancient strata of the carboniferous era, between 200 and 300 species of plants have been found. In these, say the authors of the "Fossil Flora*," no traces have been as yet discovered of the simplest forms of flowerless vegetation, such as Fungi, Lichens, Hepaticæ, or Mosses; while, on the contrary, there appear in their room Ferns, Lycopodiaceæ, and supposed Equisetaceæ, the most perfectly organized Cryptogamic plants. In regard to the remains of Monocotyledons of the same strata, they consist of palms and plants analogous to Dracænas, Bananas, and the Arrow Root tribe, which are the most highly developed tribes of that class. Among the Dicotyledons of the same period coniferous trees were abundant, while the fossil Stigmariæ, which accompany them, belonged probably to the most perfectly organized plants of that class, being allied to the Cactææ, or Euphorbiaceæ. "But supposing," continue the same authors, "that it could be demonstrated, that neither Coniferæ nor any other dicotyledonous plants existed in the first geological age of land plants, still the theory of progressive development would be untenable; because it would be necessary to show that Monocotyledons are inferior in dignity, or, to use a more intelligible expression, are less perfectly formed than Dicotyledons. So far is this from being the case, that if the exact equality of the two classes were not ad-

* Fossil Flora of Great Britain, by John Lindley and William Hutton, Esquires. London, 1832. Preface.

mitted, it would be a question whether Monocotyledons are not the more highly organized of the two; whether palms are not of greater dignity than oaks, and cerealia than nettles."

Vertebrated animals in the oldest strata. — The animal remains in the most ancient series of European sedimentary rocks (from the graywacke to the coal inclusive), consist chiefly of corals and testacea. Some estimate may generally be formed of the comparative extent of our information concerning the fossil remains of a particular era, by reference to the number of species of shells obtained from a particular group of strata. Some of the rarest species cannot be discovered, unless the more abundant kinds have been found again and again; and if the variety brought to light be very considerable, it proves not only great diligence of research, but a good state of preservation of the organic contents of that formation. In the older rocks, many causes of destruction have operated, of which the influence has been rendered considerable by the immense lapse of ages during which they have acted. Mechanical pressure, derangement by subterranean movements, the action of chemical affinity, the percolation of acidulous waters and other agencies, have obliterated, in a greater or less degree, all traces of organization in fossil bodies. Sometimes only obscure or unintelligible impressions are left, and the lapidifying process has often effaced not only the characters by which the species, but even those whereby the class might be determined.

The number of organic forms which have disappeared from the oldest strata, may be conjectured from the fact, that their former existence is in many cases merely revealed to us by the unequal weathering

of an exposed face of rock, by which certain parts are made to stand out in relief. As the number of species of shells found in the English series, from the graywacke to the coal inclusive, after attentive examination, amounts only to between one and two hundred, we cannot be surprised that so few examples of vertebrated animals have as yet occurred. The remains of fish, however, appear in one of the lowest members of the group. Numerous scales of fish have been found by Dr. Fleming in quarries of the old red sandstone at Clashbinnie in Perthshire, where I have myself collected them; and I have two entire skeletons of fish from the same formation in Forfarshire. These beds are decidedly older than the coal and mountain limestone of Fifeshire, which entirely destroys the theory of the precedence of the simplest forms of animals. Scales also of a tortoise, nearly allied to *trionyx*, occur abundantly in the bituminous schists of Caithness, and in the same formation in the Orkneys in Scotland. Professor Sedgwick and Mr. Murchison confidently pronounce these schists to be of the age of the old red sandstone; so that we have here an example of a fossil reptile in rocks referred to the oldest part of the carboniferous series.*

The only negative fact, therefore, remaining in support of the doctrine of the imperfect development of the higher orders of animals in remote ages, is the absence of birds and mammalia. The former are generally wanting in deposits of all ages, even where the highest order of animals occurs in abundance. Land mammifera could not, as was before suggested,

* See Geol. Trans., second series, vol. iii. part 1. p. 144., and for a representation of the scales of the *Trionyx*, plate 16. of the same part.

be looked for in strata formed in an ocean interspersed with isles, such as we may suppose to have existed in the northern hemisphere, when the carboniferous rocks were formed.

As all are agreed that the ancient strata in question were subaqueous, and for the most part submarine, from what data, we may ask, do naturalists infer the non-existence or even the rarity of warm-blooded quadrupeds in the earlier ages? Have they dredged the bottom of the existing ocean throughout an area co-extensive with that occupied by the carboniferous rocks, and have they found that with the number of between one and two hundred species of shells they always obtain the remains of at least one land quadruped? Suppose our mariners were to report, that on sounding in the Indian ocean near some coral reefs, and at some distance from the land, they drew up on hooks attached to their line portions of a leopard, elephant, or tapir, should we not be sceptical as to the accuracy of their statements? and if we had no doubt of their veracity, might we not suspect them to be unskilful naturalists? or, if the fact were unquestioned, should we not be disposed to believe that some vessel had been wrecked on the spot?

The casualties must be rare indeed whereby land quadrupeds are swept by rivers and torrents into the open sea, and still rarer the contingency of such a floating body not being devoured by sharks or other predaceous fish, such as were those of which we find the teeth preserved in some of the carboniferous strata.* But if the carcass should escape, and should

* I have seen in the collection of Dr. Fleming, the teeth of carnivorous fish from the mountain limestone of Fife, which alternates with the coal.

happen to sink where sediment was in the act of accumulating, and if the numerous causes of subsequent disintegration should not efface all traces of the body included for countless ages in solid rock, is it not contrary to all calculation of chances that we should hit upon the exact spot, — that mere point in the bed of an ancient ocean, where the precious relic was entombed? Can we expect for a moment, when we have only succeeded, amidst several thousand fragments of corals and shells, in finding a few bones of *aquatic* or *amphibious* animals, that we should meet with a single skeleton of an inhabitant of the land?

Clarence, in his dream, saw, “in the slimy bottom of the deep,”

—— a thousand fearful wrecks ;
A thousand men, that fishes gnaw'd upon ;
Wedges of gold, great anchors, heaps of pearl.

Had he also beheld, amid “the dead bones that lay scattered by,” the carcasses of lions, deer, and the other wild tenants of the forest and the plain, the fiction would have been deemed unworthy of the genius of Shakspeare. So daring a disregard of probability and violation of analogy would have been condemned as unpardonable, even where the poet was painting those incongruous images which present themselves to a disturbed imagination during the visions of the night.

Organic remains of the secondary strata. — The organic contents of the secondary strata in general consist of corals and marine shells. Of the latter, the European strata (from the inferior oolite to the chalk inclusive) have yielded above one thousand species. Vertebrated animals are very abundant, but they are

almost entirely confined to fish and reptiles. But some remains of cetacea are said to have been met with in the oolitic series of England*; and it is well established, that in the same series the bones of two species of warm-blooded quadrupeds of extinct genera allied to the Opossum† have been found. The occurrence of one individual of the higher classes of mammalia, whether marine or terrestrial, in these ancient strata, is as fatal to the theory of successive development as if several hundreds had been discovered.

Of the Tertiary strata. — The tertiary strata, as will appear from what we have already stated, were deposited when the physical geography of the northern hemisphere had been entirely altered. Large inland lakes had become numerous, as in Central France and many other countries. There were gulfs of the sea, into which large rivers emptied themselves, where strata were formed like those of the Paris basin. There were then also littoral formations in progress, such as are indicated by the English *Crag*, and the *Faluns* of the Loire. The state of preservation of the organic

* On the authority of Dr. Buckland. Trans. Geol. Soc. vol. i. part 2. second series, p. 394.

† The mammiferous remains of the Stonesfield slate, near Oxford, consist of three or perhaps four jaws, one of which, now in the Oxford Museum, has been examined by M. Cuvier, who has pronounced it to be allied to the Didelphis. Another of these valuable fossils, in the possession of my friend Mr. Broderip, appears to be not only specifically, but generically distinct, from that shown to M. Cuvier. See Observations on the Jaw of a Fossil Mammiferous Animal found in the Stonesfield Slate, by W. J. Broderip, Esq. Sec. G.S., F.R.S., F.L.S., &c. Zool. Journ. vol. iii, p. 408. 1827. — June, 1833. I have just been informed by Dr. Buckland, that a new jaw of a mammiferous animal has been discovered in the quarries of Stonesfield,

remains of this period is very different from that of fossils in the older rocks, the colours of the shells, and even the cartilaginous ligaments uniting the valves, being in some cases retained. More than 1100 species of testacea have been found in the beds of the Paris basin, and an equal number in the more modern formations of the Subapennine hills; and it is a most curious fact in natural history, that the zoologist has already acquired more extensive information concerning the testacea which inhabited the ancient seas of northern latitudes at those remote epochs than of the species now living in the same parallels in Europe.

Paris basin.—The strata of the Paris basin are partly of fresh-water origin, and filled with the spoils of the land. They have afforded a great number of skeletons of land quadrupeds, but these relics are confined almost entirely to one small member of the group*, and their conservation may be considered as having arisen from some local and accidental combination of circumstances. On the other hand, the scarcity of terrestrial mammalia in submarine sediment is elucidated, in a striking manner, by the extremely small number of such remains hitherto procured from the calcaire grossier, one of the formations of the Parisian series.†

Subapennine beds.—Although the Subapennine strata have been examined by collectors for three hundred years, and have yielded twelve hundred species of testacea, the authenticated examples of associated remains of terrestrial mammalia are extremely scanty; and several of those which have been cited by earlier writers as belonging to the elephant or rhinoceros,

* Book iv. ch. xviii.

† Ibid.

have since been declared, by able anatomists, to be the bones of whales and other cetacea. In about five or ten instances, perhaps, bones of the mastodon, rhinoceros, and some other land animals, have been observed in this formation with marine shells attached. These must have been washed into the bed of the ancient sea when the strata were forming, and they serve to attest the contiguity of land inhabited by large herbivora, which renders the rarity of such exceptions more worthy of attention. On the contrary, the number of skeletons of existing animals in the upper Val d'Arno, which have been usually considered to be referrible to the same age as the Subapennine beds, occur in a deposit which was formed entirely in an inland lake, surrounded by lofty mountains.*

London clay—Plastic clay.—The inferior member of our oldest tertiary formation in England, usually termed the plastic clay, has hitherto proved as destitute of mammiferous remains as our ancient coal strata; and this point of resemblance between these deposits is the more worthy of observation, because the lignite, in the one case, and the coal in the other, are exclusively composed of terrestrial plants. From the London clay we have procured three or four hundred species of testacea, but the only bones of vertebrated animals are those of reptiles and fish. On comparing, therefore, the contents of these marine strata with those of our oolitic series, we find the supposed order of precedence inverted. In the more ancient system of rocks, mammalia, both of the land and sea, have been recognized; whereas in the newer, if negative evidence is to be our criterion, Nature has made a

* See Book iv. ch. xvi.

retrograde, instead of an advancing movement, and no animals more exalted in the scale of organization than reptiles are discoverable. I should state, however, that in a fresh-water formation, resting upon the London clay, in the Isle of Wight, and like it belonging to the Eocene epoch, some mammiferous remains have recently been found.*

Not a single bone of any quadrumanous animal has ever yet been discovered in a fossil state; and their absence has appeared, to some geologists, to countenance the idea that the type of organization most nearly resembling the human came last in the order of creation, and was scarcely perhaps anterior to that of man. But the evidence on this point is quite inconclusive; for, first, we know nothing, as yet, of the details of the various classes of the animal kingdom which may have inhabited the land when the secondary strata were accumulated; and in regard to some of the more modern tertiary periods, the climate does not appear to have been of such a tropical character as may have been necessary for the development of the tribe of apes, monkeys, and allied genera. Besides, it must not be forgotten, that almost all the animals which occur in subaqueous deposits are such as frequent marshes, rivers, or the borders of lakes, as the rhinoceros, tapir, hippopotamus, ox, deer, pig, and others. On the other hand, species which live in trees are extremely rare in a fossil state; and we have no data as yet for determining how great a number of the one kind we ought to find, before we have a right to expect a single individual of the other. If, therefore, we are led to infer, from the presence of crocodiles

* Buckland and Allan, Jameson's Ed. Phil. Journ. No. 27. p. 190. Pratt, Proceedings of Geol. Soc. No. 18. 1831.

and turtles in the London clay, and from the cocoa-nuts and spices found in the Isle of Sheppey, that at the period when our older or Eocene tertiary strata were formed, the climate was hot enough for the quadrumanous tribe, we nevertheless could not hope to discover any of their skeletons until we had made considerable progress in ascertaining what were the contemporary Pachydermata; and a very small number of these have, as was before remarked, been hitherto discovered in any strata of this epoch in England.

The result then, of our inquiry into the evidence of the successive development of the animal and vegetable kingdoms, may be stated in a few words. In regard to plants, if we neglect the obscure and ambiguous impressions found in some of the oldest fossiliferous rocks, which can lead to no safe conclusions, we may consider those which characterize the great carboniferous group as the first deserving our attention. They are by no means confined to the simplest forms of vegetation, as to cryptogamic plants; but, on the contrary, belong to all the leading divisions of the vegetable kingdom; some of the more fully developed forms, both of the dicotyledonous and monocotyledonous class, having already been discovered, in the first three or four hundred species brought to light; it is therefore superfluous to pursue this part of the argument farther.

If we then examine the animal remains from the same group of rocks, we find in one of the lowest members, the old red sandstone, skeletons of fish and scales of tortoises; in other words, we have already vertebrated animals in the most ancient formation of which we can be said to have any accurate paleontological knowledge.

In regard to birds and quadrupeds, their remains are almost entirely wanting in *marine* deposits of every era, even where interposed fresh-water strata contain such fossils in abundance, as in the Paris basin. The secondary strata of Europe are for the most part marine, and there is as yet only one instance of the occurrence of mammiferous fossils in them, four or five individuals having been found in the slate of Stonesfield, a rock unquestionably of the oolitic period, and which appears, from several other circumstances, to have been formed near the point where some river entered the sea.

When we examine the tertiary groups, we find in the Eocene or oldest strata of that class the remains of a great assemblage of the highest or mammiferous class, all of extinct species, and in the Miocene beds, or those of a newer tertiary epoch, other forms, for the most part of lost species, and almost entirely distinct from the Eocene tribes. Another change is again perceived, when we investigate the fossils of later or Pliocene periods. But in this succession of quadrupeds, we cannot detect any signs of a progressive development of organization, or any indication that the Eocene fauna was less perfect than the Miocene, or this than what will be designated in the fourth book, the Newer Pliocene.

Recent origin of man.—If then there be no solid foundation in geological facts for the popular theory of the successive development of the animal and vegetable world, from the simplest to the most perfect forms; it may be asked, whether the recent origin of man lends any support to the same doctrine, or how far the influence of man may be considered as

such a deviation from the analogy of the order of things previously established, as to weaken our confidence in the uniformity of the course of nature.

I need not dwell on the proofs of the low antiquity of our species, for it is not controverted by any experienced geologist; indeed, the real difficulty consists in tracing back the signs of man's existence on the earth to that comparatively modern period when species, now his contemporaries, began to predominate. If there be a difference of opinion respecting the occurrence in certain deposits of the remains of man and his works, it is always in reference to strata confessedly of the most modern order; and it is never pretended that our race co-existed with assemblages of animals and plants, of which *all or even a great part of the species* are extinct. From the concurrent testimony of history and tradition, we learn that parts of Europe, now the most fertile and most completely subjected to the dominion of man, were, less than three thousand years ago, covered with forests, the abode of wild beasts. The archives of nature are in perfect accordance with historical records; and when we lay open the most superficial covering of peat, we sometimes find therein the canoes of the savage, together with huge antlers of the wild stag, or horns of the wild bull. In caves now open to the day in various parts of Europe, the bones of large beasts of prey occur in abundance; and they indicate that, at periods comparatively modern in the history of the globe, the ascendancy of man, if he existed at all, had scarcely been felt by the brutes.*

* Respecting the probable antiquity assignable to certain human bones and works of art found intermixed with remains of extinct animals in several localities in France, see Book iii. ch. xiv.

No inhabitant of the land exposes himself to so many dangers on the waters as man, whether in a savage or a civilized state*; and there is no animal, therefore, whose skeleton is so liable to become imbedded in lacustrine or submarine deposits: nor can it be said that his remains are more perishable than those of other animals; for in ancient fields of battle, as Cuvier has observed, the bones of men have suffered as little decomposition as those of horses which were buried in the same grave.† But even if the more solid parts of our species had disappeared, the impression of their form would have remained engraven on the rocks, as have the traces of the tenderest leaves of plants, and the integuments of many animals. Works of art, moreover, composed of the most indestructible materials, would have outlasted almost all the organic contents of sedimentary rocks. Edifices, and even entire cities, have, within the times of history, been buried under volcanic ejections, submerged beneath the sea, or engulfed by earthquakes; and had these catastrophes been repeated throughout an indefinite lapse of ages, the high antiquity of man would have been inscribed in far more legible characters on the framework of the globe than are the forms of the ancient vegetation which once covered the isles of the northern ocean, or of those gigantic reptiles which at later periods peopled the seas and rivers of the northern hemisphere.‡

Dr. Prichard has argued that the human race have not always existed on the surface of the earth, because “the strata of which our continents are composed

* See Book iii. ch. xvi.

† Ibid.

‡ Ibid.

were once a part of the ocean's bed" — "mankind had a beginning, since we can look back to the period when the surface on which they lived began to exist." * This proof, however, is insufficient, for many thousands of human beings now dwell in various quarters of the globe where marine species lived within the times of history, and, on the other hand, the sea now prevails permanently over large districts once inhabited by thousands of human beings. Nor can this interchange of sea and land ever cease while the present causes are in existence. A terrestrial species, therefore, may be older than the continents which it inhabits, and aquatic animals and plants may be of higher antiquity than the lakes and seas which they people.

Doctrine of successive development not confirmed by the admission that man is of modern origin. — It is on other grounds that we are entitled to infer that man is, comparatively speaking, of modern origin ; and if this be assumed, we may then ask whether his introduction can be considered as one step in a progressive system by which, as some suppose, the organic world advanced slowly from a more simple to a more perfect state ? In reply to this question, it should first be observed that the superiority of man depends not on those faculties and attributes which he shares in common with the inferior animals, but on his reason, by which he is distinguished from them. When it is said that the human race is of far higher dignity than were any pre-existing beings on the earth, it is the intellectual and moral attributes only of our race, not the animal, which are considered ; and it is by no means clear, that the organization of man is such as would

* Phys. Hist. of Mankind, vol. ii. p. 594.

confer a decided pre-eminence upon him, if, in place of his reasoning powers, he was merely provided with such instincts as are possessed by the lower animals.

If this be admitted, it would by no means follow, even if there had been sufficient geological evidence in favour of the theory of progressive development, that the creation of man was the last link in the same chain. For the sudden passage from an irrational to a rational animal is a phenomenon of a distinct kind from the passage from the more simple to the more perfect forms of animal organization and instinct. To pretend that such a step, or rather leap, can be part of a regular series of changes in the animal world, is to strain analogy beyond all reasonable bounds.

Introduction of man to what extent a change in the system. — But setting aside the question of progressive development, another and a far more difficult one may arise out of the admission that man is comparatively of modern origin. Is not the interference of the human species, it may be asked, such a deviation from the antecedent course of physical events, that the knowledge of such a fact tends to destroy all our confidence in the uniformity of the order of nature, both in regard to time past and future? If such an innovation could take place after the earth had been exclusively inhabited for thousands of ages by inferior animals, why should not other changes as extraordinary and unprecedented happen from time to time? If one new cause was permitted to supervene, differing in kind and energy from any before in operation, why may not others have come into action at different epochs? Or what security have we that they may not arise hereafter? And if such be the case, how can the experience of one period, even though

we are acquainted with all the possible effects of the then existing causes, be a standard to which we can refer all natural phenomena of other periods?

Now these objections would be unanswerable, if adduced against one who was contending for the absolute uniformity throughout all time of the succession of sublunary events—if, for example, he was disposed to indulge in the philosophical reveries of some Egyptian and Greek sects, who represented all the changes both of the moral and material world as repeated at distant intervals, so as to follow each other in their former connexion of place and time. For they compared the course of events on our globe to astronomical cycles; and not only did they consider all sublunary affairs to be under the influence of the celestial bodies, but they taught that on the earth, as well as in the heavens, the same identical phenomena recurred again and again in a perpetual vicissitude. The same individual men were doomed to be re-born, and to perform the same actions as before; the same arts were to be invented, and the same cities built and destroyed. The Argonautic expedition was destined to sail again with the same heroes, and Achilles with his myrmidons to renew the combat before the walls of Troy.

*Alter erit tum Tiphys, et altera quæ vehat Argo
Dilectos heroas: erunt etiam altera bella,
Atque iterum ad Trojam magnus mittetur Achilles.**

The geologist, however, may condemn these tenets as absurd, without running into the opposite extreme,

* Virgil, *Eclog.* iv. For an account of these doctrines, see Dugald Stewart's *Elements of the Philosophy of the Human Mind*, vol. ii. chap. ii. sect. 4. and Prichard's *Egypt. Mythol.* p. 177.

and denying that the order of nature has, from the earliest periods, been uniform in the same sense in which we believe it to be uniform at present, and expect it to remain so in future. We have no reason to suppose, that when man first became master of a small part of the globe, a greater change took place in its physical condition than is now experienced when districts, never before inhabited, become successively occupied by new settlers. When a powerful European colony lands on the shores of Australia, and introduces at once those arts which it has required many centuries to mature ; when it imports a multitude of plants and large animals from the opposite extremity of the earth, and begins rapidly to extirpate many of the indigenous species, a mightier revolution is effected in a brief period than the first entrance of a savage horde, or their continued occupation of the country for many centuries, can possibly be imagined to have produced. If there be no impropriety in assuming that the system is uniform when disturbances so unprecedented occur in certain localities, we can with much greater confidence apply the same language to those primeval ages when the aggregate number and power of the human race, or the rate of their advancement in civilization, must be supposed to have been far inferior. In reasoning on the state of the globe immediately before our species was called into existence, we must be guided by the same rules of induction as when we speculate on the state of America in the interval that elapsed between the introduction of man into Asia, the supposed cradle of our race, and the arrival of the first adventurers on the shores of the New World. In that interval, we imagine the state of things to have gone on according to the order now observed in regions un-

occupied by man. Even now, the waters of lakes, seas, and the great ocean, which teem with life, may be said to have no immediate relation to the human race—to be portions of the terrestrial system of which man has never taken, nor ever can take, possession ; so that the greater part of the inhabited surface of the planet remains still as insensible to our presence, as before any isle or continent was appointed to be our residence.

If the barren soil around Sidney had at once become fertile upon the landing of our first settlers ; if, like the happy isles whereof the poets have given us such glowing descriptions, those sandy tracts had begun to yield spontaneously an annual supply of grain, we might then, indeed, have fancied alterations still more remarkable in the economy of nature to have attended the first coming of our species into the planet. Or if, when a volcanic island like Ischia was, for the first time, brought under cultivation by the enterprise and industry of a Greek colony, the internal fire had become dormant, and the earthquake had remitted its destructive violence, there would then have been some ground for speculating on the debilitation of the subterranean forces, when the earth was first placed under the dominion of man. But after a long interval of rest, the volcano bursts forth again with renewed energy, annihilates one half of the inhabitants, and compels the remainder to emigrate. The course of nature remains evidently unchanged ; and, in like manner, we may suppose the general condition of the globe, immediately before and after the period when our species first began to exist, to have been the same with the exception only of man's presence.

The modifications in the system of which man is

the instrument, do not, in all probability, constitute so great a deviation from analogy as we usually imagine: we often, for example, form an exaggerated estimate of the extent of our power in extirpating some of the inferior animals, and causing others to multiply; a power which is circumscribed within certain limits, and which, in all likelihood, is by no means exclusively exerted by our species.* The growth of human population cannot take place without diminishing the numbers, or causing the entire destruction, of many animals. The larger carnivorous species give way before us, but other quadrupeds of smaller size, and innumerable birds, insects, and plants, which are inimical to our interests, increase in spite of us, some attacking our food, others our raiment and persons, and others interfering with our agricultural and horticultural labours. We behold the rich harvest which we have raised with the sweat of our brow devoured by myriads of insects, and are often as incapable of arresting their depredations, as of staying the shock of an earthquake, or the course of a stream of lava.

A great philosopher has observed, that we can only command nature by obeying her laws; and this principle is true even in regard to the astonishing changes which are superinduced in the qualities of certain animals and plants by domestication and garden culture. We shall point out in the third book that we can only effect such surprising alterations by assisting the development of certain instincts, or by availing ourselves of that mysterious law of their organization, by which individual peculiarities are transmissible from one generation to another.†

* See Book iii. ch. ix.

† Id. ch. iii.

It is probable from these, and many other considerations*, that as we enlarge our knowledge of the system, we shall become more and more convinced, that the alterations caused by the interference of man deviate far less from the analogy of those effected by other animals than we usually suppose. We are often misled, when we institute such comparisons, by our knowledge of the wide distinction between the instincts of animals and the reasoning power of man; and we are apt hastily to infer, that the effects of a rational and an irrational species, considered merely *as physical agents*, will differ almost as much as the faculties by which their actions are directed.

I am not, however, contending that a real departure from the antecedent course of physical events cannot be traced in the introduction of man. If that latitude of action which enables the brutes to accommodate themselves in some measure to accidental circumstances, could be imagined to have been at any former period so great, that the operations of instinct were as much diversified as are those of human reason, it might, perhaps, be contended, that the agency of man did not constitute an anomalous deviation from the previously established order of things. It might then have been said, that the earth's becoming at a particular period the residence of human beings, was an era in the moral, not in the physical world—that our study and contemplation of the earth, and the laws which govern its animate productions, ought no more to be considered in the light of a disturbance or deviation from the system, than the discovery of the satellites of Jupiter should be regarded as a physical event affect-

* See Book iii. chapters v. vi. vii. and ix.

ing those heavenly bodies. Their influence in advancing the progress of science among men, and in aiding navigation and commerce, was accompanied by no reciprocal action of the human mind upon the economy of nature in those distant planets; and so the earth might be conceived to have become, at a certain period, a place of moral discipline, and intellectual improvement to man, without the slightest derangement of a previously existing order of change in its animate and inanimate productions.

The distinctness, however, of the human from all other species, considered merely as an efficient cause in the physical world, is real; for we stand in a relation to contemporary species of animals and plants widely different from that which other irrational animals can ever be supposed to have held to each other. We modify their instincts, relative numbers, and geographical distribution, in a manner superior in degree, and in some respects very different in kind, from that in which any other species can affect the rest. Besides, the progressive movement of each successive generation of men causes the human species to differ more from itself in power at two distant periods, than any one species of the higher order of animals differs from another. The establishment, therefore, by geological evidence of the first intervention of such a peculiar and unprecedented agency, long after other parts of the animate and inanimate world existed, affords ground for concluding that the experience during thousands of ages of all the events which may happen on this globe would not enable a philosopher to speculate with confidence concerning future contingencies.

If then an intelligent being, after observing the

order of events for an indefinite series of ages, had witnessed at last so wonderful an innovation as this, to what extent would his belief in the regularity of the system be weakened?—would he cease to assume that there was permanency in the laws of nature?—would he no longer be guided in his speculations by the strictest rules of induction? To these questions it may be answered, that had he previously presumed to dogmatize respecting the absolute uniformity of the order of nature, he would undoubtedly be checked by witnessing this new and unexpected event, and would form a more just estimate of the limited range of his own knowledge, and the unbounded extent of the scheme of the universe. But he would soon perceive that no one of the fixed and constant laws of the animate or inanimate world was subverted by human agency, and that the modifications produced were on the occurrence of new and extraordinary circumstances, and those not of a *physical* but a *moral* nature. The deviation permitted would also appear to be as slight as was consistent with the accomplishment of the new *moral* ends proposed, and to be in a great degree temporary in its nature, so that whenever the power of the new agent was withheld, even for a brief period, a relapse would take place to the ancient state of things; the domesticated animal, for example, recovering in a few generations its wild instinct, and the garden-flower and fruit-tree reverting to the likeness of the parent stock.

Now, if it would be reasonable to draw such inferences with respect to the future, we cannot but apply the same rules of induction to the past. We have no right to anticipate any modifications in the results of existing causes in time to come, which are not con-

formable to analogy, unless they be produced by the progressive development of human power, or perhaps by some other new relations which may hereafter spring up between the moral and material worlds. In the same manner, when we speculate on the vicissitudes of the animate and inanimate creation in former ages, we ought not to look for any anomalous results, unless where man has interfered, or unless clear indications appear of some other *moral* source of temporary derangement.

For the discussion of other popular objections advanced against the doctrine of the identity of the ancient and modern causes of change, especially those founded on the supposed suddenness of general catastrophes, and the transition from one set of organic remains to another, I must refer the reader to the 4th Book. In the mean time, when difficulties arise in interpreting the monuments of the past, I deem it more consistent with philosophical caution to refer them to our present ignorance of all the existing agents, or all their possible effects in an indefinite lapse of time, than to causes formerly in operation, but which have ceased to act; and if in any part of the globe the energy of a cause appears to have decreased, I consider it more probable that the diminution of intensity in its action is merely local, than that its force is impaired throughout the whole globe. But should there appear reason to believe that certain agents have, at particular periods of past time, been more potent instruments of change over the entire surface of the earth than they now are, it is still more consistent with analogy to presume, that after an interval of quiescence they will recover their pristine vigour, than to imagine that they are worn out.

The geologist who assents to the truth of these principles will deem it incumbent on him to examine with minute attention all the changes now in progress on the earth, and will regard every fact collected respecting the causes in diurnal action as affording him a key to the interpretation of some mystery in the archives of remote ages. His estimate of the value of geological evidence, and his interest in the investigation of the earth's history, will depend entirely on the degree of confidence which he feels in regard to the permanency of the great causes of change. Their constancy alone will enable him to reason from analogy, and to arrive, by a comparison of the state of things at distinct epochs, at the knowledge of the general laws which govern the economy of our system.

The uniformity of the plan being once assumed, events which have occurred at the most distant periods in the animate and inanimate world will be acknowledged to throw light on each other, and the deficiency of our information respecting some of the most obscure parts of the present creation will be removed. For as, by studying the external configuration of the existing land and its inhabitants, we may restore in imagination the appearance of the ancient continents which have passed away, so may we obtain from the deposits of ancient seas and lakes an insight into the nature of the subaqueous processes now in operation, and of many forms of organic life, which, though now existing, are veiled from sight. Rocks, also produced by subterranean fire in former ages at great depths in the bowels of the earth, present us, when upraised by gradual movements, and exposed to the light of heaven, with an image of those changes which the deep-seated

volcano may now occasion in the nether regions. Thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is not only enabled to number worlds beyond the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and is not even withheld from penetrating into the dark secrets of the ocean, or the interior of the solid globe; free, like the spirit which the poet described as animating the universe,

——— ire per omnes
Terrasque, tractusque maris, cœlumque profundum.

BOOK II.

CHANGES OF THE INORGANIC WORLD.

PART I.—AQUEOUS CAUSES.

CHAPTER I.

Division of the subject into changes of the organic and inorganic world — Inorganic causes of change divided into aqueous and igneous — Aqueous causes first considered — Destroying and transporting power of running water — Sinuosities of rivers — Two streams when united do not occupy a bed of double surface — Heavy matter removed by torrents and floods — Recent inundations in Scotland — Effects of glaciers and icebergs in removing stones — Erosion of chasms through hard rocks — Excavations in the lavas of Etna by Sicilian rivers — Gorge of the Simeto — Gradual recession of the cataracts of Niagara.

Division of the subject. — GEOLOGY was defined to be the science which investigates the former changes that have taken place in the organic, as well as in the inorganic kingdoms of nature; and we may next proceed to inquire what changes are now in progress in both these departments. Vicissitudes in the inorganic world are most apparent; and as on them all fluctuations in the animate creation must in a great measure depend, they may claim our first consideration. The great agents of change in the inorganic world may be divided into two principal classes, the aqueous and the igneous. To the aqueous belong Rivers, Torrents, Springs, Currents, and Tides; to the igneous,

Volcanos and Earthquakes. Both these classes are instruments of decay as well as of reproduction; but they may be also regarded as antagonist forces. For the aqueous agents are incessantly labouring to reduce the inequalities of the earth's surface to a level; while the igneous are equally active in restoring the unevenness of the external crust, partly by heaping up new matter in certain localities, and partly by depressing one portion, and forcing out another, of the earth's envelope.

It is difficult, in a scientific arrangement, to give an accurate view of the combined effects of so many forces in simultaneous operation; because, when we consider them separately, we cannot easily estimate either the extent of their efficacy, or the kind of results which they produce. We are in danger, therefore, when we attempt to examine the influence exerted singly by each, of overlooking the modifications which they produce on one another; and these are so complicated, that sometimes the igneous and aqueous forces co-operate to produce a joint effect, to which neither of them unaided by the other could give rise,—as when repeated earthquakes unite with running water to widen a valley; or when a thermal spring rises up from a great depth, and conveys the mineral ingredients with which it is impregnated from the interior of the earth to the surface. Sometimes the organic combine with the inorganic causes; as when a reef, composed of shells and corals, protects one line of coast from the destroying power of tides or currents, and turns them against some other point; or when drift timber, floated into a lake, fills a hollow to which the stream would not have had sufficient velocity to convey earthy sediment.

It is necessary, however, to divide our observations on these various causes, and to classify them systematically, endeavouring as much as possible to keep in view that the effects in nature are mixed, and not simple, as they may appear in an artificial arrangement.

In treating, in the first place, of the aqueous causes we may consider them under two divisions : first, those which are connected with the circulation of water from the land to the sea, under which are included all the phenomena of rivers and springs; secondly, those which arise from the movements of water in lakes, seas, and the ocean, wherein are comprised the phenomena of tides and currents. In turning our attention to the former division, we find that the effects of rivers may be subdivided into those of a destroying and those of a renovating nature. In the destroying class are included the erosion of rocks, and the transportation of matter to lower levels; in the renovating, the formation of sand-bars and deltas, the shallowing of seas, &c.

Action of running water. —I shall begin, then, by describing the destroying and transporting power of running water, as exhibited by torrents and rivers. It is well known that the lands elevated above the sea attract, in proportion to their volume and density, a larger quantity of that aqueous vapour which the heated atmosphere continually absorbs from the surface of lakes and the ocean. By these means, the higher regions become perpetual reservoirs of water, which descend and irrigate the lower valleys and plains. In consequence of this provision, almost all the water is first carried to the highest regions, and is then made to descend by steep declivities towards the sea; so that it acquires superior velocity, and removes a greater quantity of soil, than it would do if the rain

had been distributed over the plains and mountains equally in proportion to their relative areas. Almost all the water is also made by these means to pass over the greatest distances which each region affords, before it can regain the sea. The rocks also, in the higher regions, are particularly exposed to atmospheric influences, to frost, rain, and vapour, and to great annual alternations of cold and heat, of moisture and desiccation.

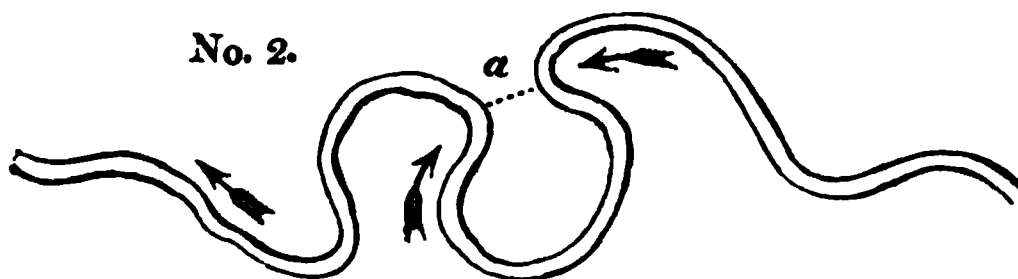
Its destroying and transporting power. — Among the most powerful agents of decay may be mentioned that property of water which causes it to expand during congelation. When water has penetrated into crevices, it rends open, on freezing, the most solid rocks with the mechanical force of a lever ; and for this reason, although in cold climates the comparative quantity of rain which falls is very inferior, and although it descends more gradually than in tropical regions, yet the severity of frost, and the greater inequalities of temperature, compensate in some degree for this diminished source of degradation. The solvent power of water also is very great, and acts particularly on the calcareous and alkaline elements of stone, especially when it holds carbonic acid in solution, which is abundantly supplied to almost every large river by springs, and is collected by rain from the atmosphere. The oxygen of the atmosphere is also gradually absorbed by all animal and vegetable productions, and by almost all mineral masses exposed to the open air. It gradually destroys the equilibrium of the elements of rocks, and tends to reduce into powder, and to render fit for soils, even the hardest aggregates belonging to our globe.*

* Sir H. Davy, *Consolations in Travel*, p. 271.

When earthy matter has once been intermixed with running water, a new mechanical power is obtained by the attrition of sand and pebbles, borne along with violence by a stream. Running water charged with foreign ingredients being thrown against a rock, excavates it by mechanical force, sapping and undermining till the superincumbent portion is at length precipitated into the stream. The obstruction causes a temporary increase of the water, which then sweeps down the barrier.

Sinuosity of Rivers.—By a repetition of these landslips, the ravine is widened into a small, narrow valley, in which sinuosity is caused by the deflexion of the stream first to one side and then to the other. The unequal hardness of the materials through which the channel is eroded, tends partly to give new directions to the lateral force of excavation. When by these, or by accidental shiftings of the alluvial matter in the channel, and numerous other causes, the current is made to cross its general line of descent, it eats out a curve in the opposite bank, or in the side of the hills bounding the valley, from which curve it is turned back again at an equal angle, so that it recrosses the line of descent, and gradually hollows out another curve lower down in the opposite bank, till the whole sides of the valley, or river-bed, present a succession of salient and retiring angles. Among the causes of deviation from a straight course by which torrents and rivers tend in mountainous regions to widen the valleys through which they flow, may be mentioned the confluence of lateral torrents, swollen irregularly at different seasons by partial storms, and discharging at different times unequal quantities of debris into the main channel.

When the tortuous flexures of a river are extremely great, the aberration from the direct line of descent is often restored by the river cutting through the isthmus which separates two neighbouring curves. Thus, in the annexed diagram, the extreme sinuosity of



the river has caused it to return for a brief space in a contrary direction to its main course, so that a peninsula is formed, and the isthmus (at *a*) is consumed on both sides by currents flowing in opposite directions. In this case an island is soon formed, — on either side of which a portion of the stream usually remains.* These windings occur not only in the channels of rivers, flowing like the Mississippi through flat alluvial plains, but large valleys also are excavated to a great depth through solid rocks in this serpentine form. In the valley of the Moselle, between Berncastle and Roarn, which is sunk to a depth of from six to eight hundred feet through an elevated platform of transition rocks, the curves are so considerable that the river returns after a course of seventeen miles in one instance; and nearly as much in two others, to within a distance of a few hundred yards of the spot it passed before.† The valley of the Meuse, near Givet, and many others

* See a Paper on the Excavation of Valleys, &c. by G. Poulett Scrope, Esq. Proceedings of Geol. Soc. No. 14., 1830.

† Ibid.

in different countries, offer similar windings. Mr. Scrope has remarked, that these tortuous flexures are decisively opposed to the hypothesis, that any violent and transient rush of water suddenly swept out such valleys; for great floods would produce straight channels in the direction of the current, not sinuous excavations, wherein rivers flow back again in an opposite direction to their general line of descent.

I cannot however accede to the doctrine that the valleys of the Meuse and Moselle above alluded to were formed simply by river action; believing them, like many other deep valleys of a similar form, to have been principally due to marine currents, which acted throughout a great lapse of ages during the gradual elevation of the country.*

Transporting power of water.—In regard to the transporting power of water, we often feel surprise at the facility with which streams of a small size, and descending a slight declivity, bear along coarse sand and gravel; for we usually estimate the weight of rocks in air, and do not reflect sufficiently on their comparative buoyancy when submerged in a denser fluid. The specific gravity of many rocks is not more than twice that of water, and very rarely more than thrice, so that almost all the fragments propelled by a stream have lost a third, and many of them half, of what we usually term their weight.

It has been proved by experiment, in contradiction to the theories of the earlier writers on hydrostatics, to be a universal law, regulating the motion of running water, that the velocity at the bottom of the stream is every where less than in any part above it, and is

* For remarks on the valley of the Meuse, near St. Mihiel, alluded to in this place in a former edition, see Book iv. Ch. 10.

greatest at the surface. Also, that the superficial particles in the middle of the stream move swifter than those at the sides. This retardation of the lowest and lateral currents is produced by friction; and when the velocity is sufficiently great, the soil composing the sides and bottom gives way. A velocity of three inches per second at the bottom is ascertained to be sufficient to tear up fine clay,—six inches per second, fine sand,—twelve inches per second, fine gravel,—and three feet per second, stones of the size of an egg.*

When this mechanical power of running water is considered, we are prepared for the transportation of large quantities of gravel, sand, and mud, by the torrents and rivers which descend with great velocity from mountainous regions. But a question naturally arises, how the more tranquil rivers of the valleys and plains, flowing on comparatively level ground, can remove the prodigious burden which is discharged into them by their numerous tributaries, and by what means they are enabled to convey the whole mass to the sea. If they had not this removing power, their channels would be annually choked up, and the lower valleys and districts adjoining mountain-chains would be continually strewed over with fragments of rock and sterile sand. But this evil is prevented by a general law regulating the conduct of running water—that two equal streams do not, when united, occupy a bed of double surface. In other words, when several rivers unite into one, the superficial area of the fluid mass is far less than that previously occupied by the separate streams. The collective waters, instead of spreading

* Encycl. Brit. — art. Rivers.

themselves out over a larger horizontal space, contract themselves into a column of which the height is greater relatively to its breadth: hence a smaller proportion of the whole is retarded by friction against the bottom and sides of the channel. In this manner the main current is often accelerated in the lower country, even where the slope of the channel is lessened.

It not unfrequently happens, as will be afterwards demonstrated by examples, that two large rivers, after their junction, have only the *surface* which one of them had previously; and even in some cases their united waters are confined in a narrower bed than each of them filled before. By this beautiful adjustment, the water which drains the interior country is made continually to occupy less room as it approaches the sea; and thus the most valuable part of our continents, the rich deltas, and great alluvial plains, are prevented from being constantly under water.*

Floods in Scotland, 1829.—Many remarkable illustrations of the power of running water in moving stones and heavy materials were afforded by the storm and flood which occurred on the 3d and 4th of August, 1829, in Aberdeenshire and other counties in Scotland. The elements during this storm assumed all the characters which mark the tropical hurricanes; the wind blowing in sudden gusts and whirlwinds, the lightning and thunder being such as is rarely witnessed in our climate, and heavy rain falling without intermission. The floods extended almost simultaneously, and with equal violence, over that part of the north-east of Scotland which would be cut off by two lines drawn

* See article Rivers, Encyc. Brit.

from the head of Lochrannoch, one towards Inverness and the other to Stonehaven. The united line of the different rivers which were flooded could not be less than from five to six hundred miles in length; and the whole of their courses were marked by the destruction of bridges, roads, crops, and buildings. Sir T. D. Lauder has recorded the destruction of thirty-eight bridges, and the entire obliteration of a great number of farms and hamlets. On the Nairn, a fragment of sandstone, fourteen feet long by three feet wide and one foot thick, was carried above two hundred yards down the river. Some new ravines were formed on the sides of mountains where no streams had previously flowed, and ancient river-channels, which had never been filled from time immemorial, gave passage to a copious flood.*

The bridge over the Dee at Ballatu consisted of five arches, having upon the whole a water-way of 260 feet. The bed of the river, on which the piers rested, was composed of rolled pieces of granite and gneiss. The bridge was built of granite, and had stood uninjured for twenty years; but the different parts were swept away in succession by the flood, and the whole mass of masonry disappeared in the bed of the river.† “The river Don,” observes Mr. Farquharson, in his account of the inundations, “has upon my own premises forced a mass of four or five hundred tons of stones, many of them two or three hundred pounds weight, up an inclined plane, rising six feet in eight or ten yards, and left them in a rectangular heap,

* Sir T. D. Lauder's Account of the Great Floods in Morayshire, Aug. 1829.

† From the account given by the Rev. James Farquharson, in the Quarterly Journ. of Science, &c. No. xii. New Series, p. 328.

about three feet deep, on a flat ground;—the heap ends abruptly at its lower extremity.”*

The power even of a small rivulet, when swoln by rain, in removing heavy bodies, was lately exemplified in the College, a small stream which flows at a moderate declivity from the eastern water-shed of the Cheviot-Hills. Several thousand tons' weight of gravel and sand were transported to the plain of the Till, and a bridge then in progress of building was carried away, some of the arch-stones of which, weighing from half to three quarters of a ton each, were propelled two miles down the rivulet. On the same occasion, the current tore away from the abutment of a mill-dam a large block of greenstone-porphry, weighing nearly two tons, and transported it to the distance of a quarter of a mile. Instances are related as occurring repeatedly, in which from one to three thousand tons of gravel are, in like manner, removed by this streamlet to great distances in one day.†

In the cases above adverted to, the waters of the river and torrent were dammed back by the bridges, which acted as partial barriers, and illustrate the irresistible force of a current when obstructed. Bridges are also liable to be destroyed by the tendency of rivers to shift their course, whereby the pier, or the rock on which the foundation stands, is undermined.

When we consider how insignificant are the volume and velocity of the rivers and streams in our island, when compared to those of the Alps and other lofty chains, and how, during the successive changes which

* Quarterly Journ. of Sci. &c. No. xii. New Series, p. 331.

† See a paper by Mr. Culley, F.G.S. Proceedings of Geol. Soc. No. xii. 1829.

the levels of various districts have undergone, the contingencies which give rise to floods must have been multiplied, we may easily conceive that the quantity of loose superficial matter distributed over Europe must be considerable. That the position also of a great portion of these travelled materials should now appear most irregular, and should often bear no relation to the existing water-drainage of the country, is a necessary consequence, as we shall afterwards see, of the combined operations of running water and subterranean movements.

Effects of ice in removing stones.—In mountainous regions and high northern latitudes, the moving of heavy stones by water is greatly assisted by the ice which adheres to them, and which, forming together with the rock a mass of less specific gravity*, is readily borne along. The snow which falls on the summits of the Alps throughout nine months of the year is drifted into the higher valleys, and being pressed downward by its own weight, forms those masses of ice and snow called *glaciers*. Large portions of these often descend into the lower valleys, where they are seen in the midst of forests and green pastures. The mean depth of the glaciers descending from Mont Blanc is from 80 to 100 feet, and in some chasms is seen to amount to 600 feet.† The surface of the moving mass is usually loaded with sand, and large stones, derived from the disintegration of the surrounding rocks acted upon by frost. These transported materials are generally arranged in long ridges or mounds, sometimes 30 or 40 feet high. They are often two, three, or even

* Silliman's Journal, No. xxx. p. 303.

† Saussure, Voy. dans les Alpes, tom. i. p. 440.

more in number, like so many lines of intrenchment, and consist of the debris which have been brought in by lateral glaciers. The whole accumulation is called in Switzerland "the moraine." Being slowly conveyed to inferior valleys, it is there thrown down, when the snow and ice melt, upon the plain, where the larger blocks remain, and the smaller are swept away by the stream to which the melting of the ice gives rise. This stream flows along the bottom of each glacier, issuing from an arch at its lower extremity.

In northern latitudes, where glaciers descend into valleys terminating in the sea, great masses of ice, on arriving at the shore, are occasionally detached and floated off together with their "moraine." The currents of the ocean are then often instrumental in transporting them to great distances. Scoresby* counted 500 icebergs drifting along in latitude 69° and 70° north, which rose above the surface from the height of one to two hundred feet, and measured from a few yards to a mile in circumference. Many of these contained strata of earth and stones, or were loaded with beds of rock of great thickness, of which the weight was conjectured to be from fifty thousand to one hundred thousand tons. Such bergs must be of great magnitude; because the mass of ice below the level of the water is between seven and eight times greater than that above. Wherever they are dissolved, it is evident that the "moraine" will fall to the bottom of the sea. In this manner may submarine valleys, mountains, and platforms become strewn over with scattered blocks of foreign rock, of a nature perfectly dissimilar from all in the vicinity,

* Voyage in 1822, p. 233.

and which may have been transported across unfathomable abysses. We have before stated, that some ice islands have been known to drift from Baffin's Bay to the Azores, and from the South Pole to the immediate neighbourhood of the Cape of Good Hope.*

Excavation of rocks by running water. — The rapidity with which even the smallest streams hollow out deep channels in soft and destructible soils is remarkably exemplified in volcanic countries, where the sand and half-consolidated tuffs oppose but a slight resistance to the torrents which descend the mountain-side. After the heavy rains which followed the eruption of Vesuvius in 1822, the water flowing from the Atrio del Cavallo cut, in three days, a new chasm through strata of tuff and ejected volcanic matter to the depth of twenty-five feet. I found the old mule-road, in 1828, intersected by this new ravine.

The gradual erosion of deep chasms through some of the hardest rocks, by the constant passage of running water charged with foreign matter, is another phenomenon of which striking examples may be adduced. Illustrations of this excavating power are presented by many valleys in Central France, where the channels of rivers have been barred up by solid currents of lava, through which the streams have re-excavated a passage to the depth of from twenty to seventy feet and upwards, and often of great width. In these cases there are decisive proofs that neither the sea nor any denuding wave, or extraordinary body of water, has passed over the spot since the melted lava was consolidated. Every hypothesis of the intervention of sudden and violent agency is entirely ex-

* For farther remarks on the transporting power of glaciers, see Book iv. ch. 11.

cluded, because the cones of *loose* scorixæ, out of which the lavas flowed, are oftentimes at no great elevation above the rivers, and have remained undisturbed during the whole period which has been sufficient for the hollowing out of such enormous ravines. *

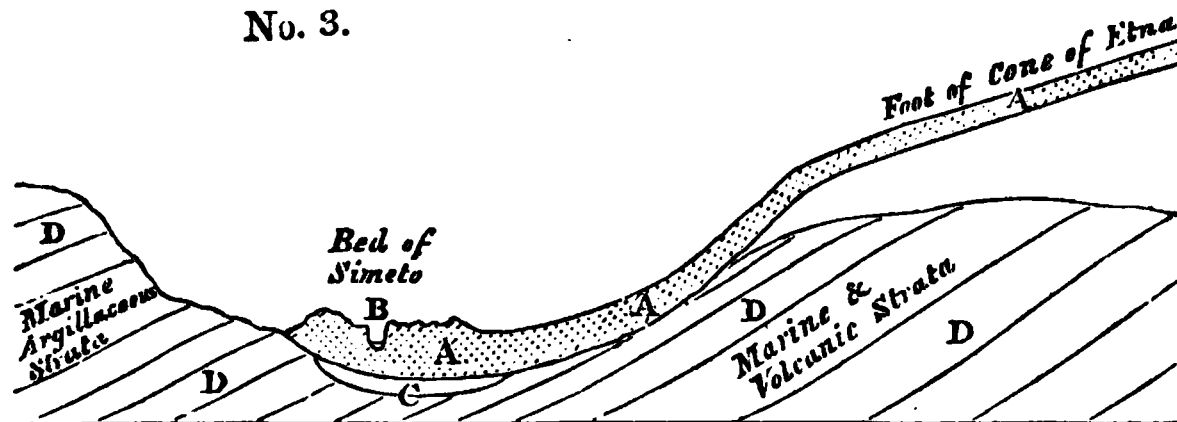
Recent excavation by the Simeto.—But I shall at present confine myself to examples derived from events which have happened since the time of history. Some lavas of Etna, produced by eruptions of which the date is known, have flowed across two of the principal rivers in Sicily; and in both cases the streams, dispossessed of their ancient beds, have opened for themselves new channels. An eruption from Mount Mojo, an insulated cone at the northern base of Etna, sent forth, in the year 396 B.C., in the reign of Dionysius I., a great lava stream, which crossed the river Caltabianca in two places. The lowermost point of obstruction is seen on the eastern side of Etna, on the high road from Giardini to Catania, where one pier of the bridge on either bank is based upon a remnant of the solid lava, which has been breached by the river to the depth of fourteen feet. But the Caltabianca, although it has been at work for more than two and twenty centuries, has not worn through the igneous rock so as to lay open the gravel of its ancient bed. The declivity, however, of the alluvial plain is very slight; and as the extent of excavation in a given time depends on the volume and velocity of the stream, and the destructibility of the rock, we must carefully ascertain all these circumstances before we attempt to deduce from such examples a measure of the force of running water in a given period.†

* See Book iv. ch. 19.

† I omitted to visit the higher point near the village of Mojo,

The power of running water to hollow out compact rock is exhibited on a larger scale at the western base of Etna, where a great current of lava (A A, diagram 3.),

No. 3.



Recent excavation of lava at the foot of Etna by the river Simeto.

descending from near the summit of the great volcano, has flowed to the distance of five or six miles, and then reached the alluvial plain of the Simeto, the largest of the Sicilian rivers, which skirts the base of Etna, and falls into the sea a few miles south of Catania. The lava entered the river about three miles above the town of Aderno, and not only occupied its channel for some distance, but, crossing to the opposite side of the valley, accumulated there in a rocky mass. Gemmellaro gives the year 1603 as the date of the eruption.* The appearance of the current clearly proves that it is one of the most modern of those of Etna; for it has not been covered or crossed by subsequent streams or ejections, and the olives on its surface are all of small size,

where the Caltabianca has cut through the lava. Some future traveller would probably derive much instruction from inspecting that spot, which is laid down in Gemmellaro's *Quadro Istorico, &c. dell' Etna*, 1824.

* *Quadro Istorico dell' Etna*, 1824. Some doubts are entertained as to the exact date of this current by others, but all agree that it is not one of the older streams even of the historical era.

yet older than the natural wood on the same lava. In the course, therefore, of about two centuries the Simeto has eroded a passage from fifty to several hundred feet wide, and in some parts from forty to fifty feet deep.

The portion of lava cut through is in no part porous or scoriaceous, but consists of a compact homogeneous mass of hard blue rock, somewhat inferior in weight to ordinary basalt, and containing crystals of olivine and glassy felspar. The general declivity of this part of the bed of the Simeto is not considerable; but, in consequence of the unequal waste of the lava, two waterfalls occur at Passo Manzanelli, each about six feet in height. Here the chasm (B, diagram No. 3.) is about forty feet deep, and only fifty broad.

The sand and pebbles in the river-bed consist chiefly of a brown quartzose sandstone, derived from the upper country; but the materials of the volcanic rock itself must have greatly assisted the attrition. This river, like the Caltabianca, has not yet cut down to the ancient bed of which it was dispossessed, and of which we have indicated the probable position in the annexed diagram (C, No. 3.).

On entering the narrow ravine where the water foams down the two cataracts, we are entirely shut out from all view of the surrounding country; and a geologist who is accustomed to associate the characteristic features of the landscape with the relative age of certain rocks, can scarcely dissuade himself from the belief that he is contemplating a scene in some rocky gorge of a primary district. The external forms of the hard blue lava are as massive as any of the most ancient trap-rocks of Scotland. The solid surface is in some parts smoothed and almost polished by attrition, and covered in others with a white lichen, which im-

parts to it an air of extreme antiquity, so as greatly to heighten the delusion. But the moment we re-ascend the cliff the spell is broken: for we scarcely recede a few paces, before the ravine and river disappear, and we stand on the black and rugged surface of a vast current of lava, which seems unbroken, and which we can trace up nearly to the distant summit of that majestic cone which Pindar called "the pillar of heaven," and which still continues to send forth a fleecy wreath of vapour, reminding us that its fires are not extinct, and that it may again give out a rocky stream, wherein other scenes like that now described may present themselves to future observers.

Falls of Niagara.—The falls of Niagara afford a magnificent example of the progressive excavation of a deep valley in solid rock. That river flows from Lake Erie to Lake Ontario, the former lake being 330 feet above the latter, and the distance between them being thirty-two miles. On flowing out of the upper lake, the river is almost on a level with its banks; so that if it should rise perpendicularly eight or ten feet, it would lay under water the adjacent flat country of Upper Canada on the West, and of the State of New York on the East.* The river, where it issues, is about three quarters of a mile in width. Before reaching the falls, it is propelled with great rapidity, being a mile broad, about twenty-five feet deep, and having a descent of fifty feet in half a mile. An island at the very verge of the cataract divides it into two sheets of water; one of these, called the Horse-shoe Fall, is six hundred yards wide, and 158 feet perpendicular; the other, called

* Captain Hall's Travels in North America, vol. i. p. 179.

the American Falls, is about two hundred yards in width, and 164 feet in height. The breadth of the island is about five hundred yards. This great sheet of water is precipitated over a ledge of hard limestone, in horizontal strata, below which is a somewhat greater thickness of soft shale, which decays and crumbles away more rapidly, so that the calcareous rock forms an overhanging mass, projecting forty feet or more above the hollow space below.

The blasts of wind, charged with spray, which rise out of the pool into which this enormous cascade is projected, strike against the shale beds, so that their disintegration is constant; and the superincumbent limestone, being left without a foundation, falls from time to time in rocky masses. When these enormous fragments descend, a shock is felt at some distance, accompanied by a noise like a distant clap of thunder. After the river has passed over the falls, its character, observes Captain Hall, is immediately and completely changed. It then runs furiously along the bottom of a deep wall-sided valley, or huge trench, which has been cut into the horizontal strata by the continued action of the stream during the lapse of ages. The cliffs on both sides are in most places perpendicular, and the ravine is only perceived on approaching the edge of the precipice.*

The waters which expand at the falls, where they are divided by the island, are contracted again, after their union, into a stream not more than 160 yards broad. In the narrow channel, immediately below this immense rush of water, a boat can pass across the

* Captain Hall's Travels in North America, vol. i. pp. 195, 196, 216.

stream with ease. The pool, it is said, into which the cataract is precipitated, being 170 feet deep, the descending water sinks down and forms an under-current, while a superficial eddy carries the upper stratum back *towards* the main fall.* This is not improbable; and we must also suppose, that the confluence of the two streams, which meet at a considerable angle, tends mutually to neutralize their forces. The bed of the river below the falls is strewn over with huge fragments which have been hurled down into the abyss. By the continued destruction of the rocks, the falls have, within the last forty years, receded nearly fifty yards, or, in other words, the ravine has been prolonged to that extent. Through this deep chasm, the Niagara flows for about seven miles; and then the table-land, which is almost on a level with Lake Erie, suddenly sinks down at a town called Queenstown, and the river emerges from the ravine into a plain which continues to the shores of Lake Ontario.†

Recession of the Falls. — There seems good foundation for the general opinion, that the falls were once at Queenstown, and that they have gradually retrograded from that place to their present position, about seven miles distant. The table-land, extending from thence to Lake Erie, consists uniformly of the same geological formations as are now exposed to view at the falls. The upper stratum is an ancient alluvial sand, varying in thickness from 10 to 140 feet; below which is a bed of hard limestone, about ninety feet in thickness,

* See Mr. Bakewell, jun. on the falls of Niagara. — Loudon's Mag. of Nat. Hist. No. xii. March, 1830.

† The memoir of Mr. Bakewell, jun. above referred to contains two very illustrative sketches of the physical geography of the country between Lakes Erie and Ontario, including the Falls.

stretching nearly in a horizontal direction over the whole country, and forming the bed of the river *above* the falls, as do the inferior shales *below*. The lower shale is nearly of the same thickness as the limestone; but this last is said to thicken at the point now reached by the falls, a circumstance which may enable it in future to offer greater resistance to the force of the cataract.*

If the ratio of recession had never exceeded fifty yards in forty years, it must have required nearly ten thousand years for the excavation of the whole ravine; but scarcely any estimate can be formed of the quantity of time consumed in such an operation, because the retrograde movement was probably much more rapid when the whole current was confined within a space not exceeding a fourth or fifth of that which the falls now occupy. Should the erosive action not be accelerated in future, it will require upwards of thirty thousand years for the falls to reach Lake Erie (twenty-five miles distant), to which they seem destined to arrive in the course of time, unless some earthquake changes the relative levels of the district.

If that great lake should remain in its present state until the period when the ravine recedes to its shores, the sudden escape of so vast a body of water might cause a tremendous deluge; for the ravine would be much more than sufficient to drain the whole lake, of which the average depth was found, during the late survey, to be only 10 or 12 fathoms. But, in consequence of its shallowness, Lake Erie is fast filling up with sediment; and a question arises, whether its entire area may not be converted into dry land, before the falls recede so far.

* Monthly American Journ. July 1831, p. 21.

CHAPTER II.

ACTION OF RUNNING WATER — *continued.*

Course of the Po — Desertion of its old channel — Artificial embankments of the Po, Adige, and other Italian rivers — Basin of the Mississippi — Its meanders — Islands — Shifting of its course — Raft of the Atchafalaya — Drift wood — New-formed lakes in Louisiana — Earthquakes in the valley of the Mississippi — Floods caused by land-slips in the White Mountains — Bursting of a lake in Switzerland — Devastations caused by the Anio at Tivoli.

Course of the Po. — THE Po affords an instructive example of the manner in which a great river bears down to the sea the matter poured into it by a multitude of tributaries descending from lofty chains of mountains. The changes gradually effected in the great plain of Northern Italy, since the time of the Roman republic, are considerable. Extensive lakes and marshes have been gradually filled up, as those near Placentia, Parma, and Cremona, and many have been drained naturally by the deepening of the beds of rivers. Deserted river-courses are not unfrequent, as that of the Serio Morto, which formerly fell into the Adda, in Lombardy; and the Po itself has often deviated from its course. Subsequently to the year 1390, it deserted part of the territory of Cremona, and invaded that of Parma; its old channel being still recognizable, and bearing the name of Po Morto. Bressello is one of the towns of which the site was formerly on the left of the Po, but which is now on the right bank. There is also an old channel

of the Po in the territory of Parma, called Po Vecchio, which was abandoned in the twelfth century, when a great number of towns were destroyed. There are records of parish-churches, as those of Vicobellignano, Agojolo, and Martignana, having been pulled down and afterwards rebuilt at a greater distance from the devouring stream. In the fifteenth century the main branch again resumed its deserted channel, and carried away a great island opposite Casalmaggiore. At the end of the same century it abandoned, a second time, the bed called "Po Vecchio," carrying away three streets of Casalmaggiore. The friars in the monastery de' Serviti took the alarm in 1471, demolished their buildings, and reconstructed them at Fontana, whither they had transported the materials. In like manner, the church of S. Rocco was demolished in 1511. In the seventeenth century also the Po shifted its course for a mile in the same district, causing great devastations.*

Artificial embankments of Italian rivers.—To check these and similar aberrations, a general system of embankment has been adopted; and the Po, Adige, and almost all their tributaries, are now confined between high artificial banks. The increased velocity acquired by streams thus closed in, enables them to convey a much larger portion of foreign matter to the sea; and, consequently, the deltas of the Po and Adige have gained far more rapidly on the Adriatic since the practice of embankment became almost universal. But although more sediment is borne to the sea, part of the sand and mud, which in the natural state of things would be spread out by annual

* Dell' Antico Corso de' Fiumi Po, Oglio, ed Adda, dell' Giovanni Romani. Milan, 1828.

inundations over the plain, now subsides in the bottom of the river-channels, and their capacity being thereby diminished, it is necessary, in order to prevent inundations in the following spring, to extract matter from the bed, and to add it to the banks, of the river. Hence it has arisen that these streams now traverse the plain on the top of high mounds, like the waters of aqueducts, and the surface of the Po has become more elevated than the roofs of the houses of the city of Ferrara.* The magnitude of these barriers is a subject of increasing expense and anxiety, it having been sometimes of late years found necessary to give an additional height of nearly one foot to the banks of the Adige and Po in a single season.

The practice of embankment was adopted on some of the Italian rivers as early as the thirteenth century; and Dante, writing in the beginning of the fourteenth, describes, in the seventh circle of hell, a rivulet of tears separated from a burning sandy desert by embankments "like those which, between Ghent and Bruges, were raised against the ocean, or those which the Paduans had erected along the Brenta to defend their villas on the melting of the Alpine snows."

Quale i Fiamminghi tra Guzzante e Bruggia,
Temendo il fiotto che in ver lor s'avventa,
Fanno lo schermo, perchè il mar si fuggia,
E quale i Padovan lungo la Brenta,
Per difender lor ville e lor castelli,
Anzi che Chiarentana il caldo senta —

Inferno, Canto xv.

Basin of the Mississippi.—The hydrographical basin of the Mississippi displays, on the grandest scale, the

* Prony, see Cuvier, Disc. Prélim. p. 146.

action of running water on the surface of a vast continent. This magnificent river rises nearly in the forty-ninth parallel of north latitude, and flows to the Gulf of Mexico in the twenty-ninth—a course, including its meanders, of nearly five thousand miles. It passes from a cold arctic climate, traverses the temperate regions, and discharges its waters into the sea in the region of the olive, the fig, and the sugar-cane.* No river affords a more striking illustration of the law before mentioned, that an augmentation of volume does not occasion a proportional increase of surface, nay, is even sometimes attended with a narrowing of the channel. The Mississippi is half a mile wide at its junction with the Missouri†; the latter being also of equal width; yet the united waters have only, from their confluence to the mouth of the Ohio, a medial width of about three quarters of a mile. The junction of the Ohio seems also to produce no increase, but rather a decrease, of surface.‡ The St. Francis, White, Arkansas, and Red rivers, are also absorbed by the main stream with scarcely any apparent increase of its width; and, on arriving near the sea at New Orleans, it is somewhat less than half a mile wide. Its depth there is very variable, the greatest at high water being 168 feet. The mean rate at which the whole body of water flows is variously estimated. According to some, it does not exceed one mile an hour.§

* Flint's Geography, vol. i. p. 21.

† Flint says (vol. i. p. 140.) that, where the Mississippi receives the Missouri, it is a mile and a half wide, but, according to Captain B. Hall, this is a great mistake. — Travels in the United States, vol. iii. p. 328.

‡ Flint's Geography, vol. i. p. 142.

§ Hall's Travels in North America, vol. iii. p. 330., who cites Darby.

The alluvial plain of this great river is bounded on the east and west by great ranges of mountains stretching along their respective oceans. Below the junction of the Ohio, the plain is from thirty to fifty miles broad, and after that point it goes on increasing in width till the expanse is perhaps three times as great! On the borders of this vast alluvial tract are perpendicular cliffs, or "bluffs," as they are called, composed of limestone and other rocks. For a great distance the Mississippi washes the eastern "bluffs;" and below the mouth of the Ohio, never once comes in contact with the western. The waters are thrown to the eastern side, because all the large tributary rivers entering from the west, have filled that side of the great valley with a sloping mass of clay and sand. For this reason, the eastern bluffs are continually undermined, and the Mississippi is slowly but incessantly progressing eastward.*

Curves of the Mississippi.—The river traverses the plain in a meandering course, describing immense and uniform curves. After sweeping round the half of a circle, it is carried in a rapid current diagonally across its own channel, to another curve of the same uniformity upon the opposite shore.† These curves are so regular, that the boatmen and Indians calculate distances by them. Opposite to each of them there is always a sand-bar, answering, in the convexity of its form, to the concavity of "the bend," as it is called.‡ The river, by continually wearing these curves deeper, returns, like many other streams before described, on its own tract, so that a vessel in

* Geograph. Descrip. of the State of Louisiana, by W. Darby. Philadelphia, 1816, p. 102.

† Flint's Geog. vol. i. p. 152.

‡ Ibid.

some places, after sailing for twenty-five or thirty miles, is brought round again to within a mile of the place whence it started. When the waters approach so near to each other, it often happens at high floods that they burst through the small tongue of land, and insulate a portion, rushing through what is called the "cut off" with great velocity. At one spot, called the "grand cut off," vessels now pass from one point to another in half a mile to a distance which it formerly required a voyage of twenty miles to reach.*

Waste of its banks.—After the flood season, when the river subsides within its channel, it acts with destructive force upon the alluvial banks, softened and diluted by the recent overflow. Several acres at a time, thickly covered with wood, are precipitated into the stream; and large portions of the islands formed by the process before described are swept away.

"Some years ago," observes Captain Hall, "when the Mississippi was regularly surveyed, all its islands were numbered, from the confluence of the Missouri to the sea; but every season makes such revolutions, not only in the number but in the magnitude and situation of these islands, that this enumeration is now almost obsolete. Sometimes large islands are entirely melted away—at other places they have attached themselves to the main shore, or, which is the more correct statement, the interval has been filled up by myriads of logs cemented together by mud and rubbish."† When the Mississippi and many of its great tributaries overflow their banks, the waters,

* Flint's Geog. vol. i. p. 154.

† Travels in North America, vol. iii. p. 361.

being no longer borne down by the main current, and becoming impeded amongst the trees and bushes, deposit the sediment of mud and sand with which they are abundantly charged. Islands arrest the progress of floating trees, and they become in this manner reunited to the land; the rafts of trees, together with mud, constituting at length a solid mass. The coarser portion subsides first, and the most copious deposition is found near the banks where the soil is most sandy. Finer particles are found at the farthest distances from the river, where an impalpable mixture is deposited, forming a stiff unctuous black soil. Hence the alluvions of these rivers are highest directly on the banks, and slope back like a natural "glacis" towards the rocky cliffs bounding the great valley.* The Mississippi, therefore, by the continual shifting of its course, sweeps away, during a great portion of the year, considerable tracts of alluvium which were gradually accumulated by the overflow of former years, and the matter now left during the spring-floods will be at some future time removed.

Raft of the Atchafalaya. — One of the most interesting features in this basin is "the raft." The dimensions of this mass of timber were given by Darby, in 1816, as ten miles in length, about 220 yards wide, and eight feet deep, the whole of which had accumulated, in consequence of some obstruction, during about thirty-eight years, in an arm of the Mississippi called the Atchafalaya, which is supposed to have been at some past time a channel of the Red River, before it intermingled its waters with the main

* Flint's Geography, vol. i. p. 151.

stream. This arm is in a direct line with the direction of the Mississippi, and it catches a large portion of the drift wood annually brought down.

The mass of timber in the raft is continually increasing, and the whole rises and falls with the water. Although floating, it is covered with green bushes, like a tract of solid land, and its surface is enlivened in the autumn by a variety of beautiful flowers.

Drift Wood. — Notwithstanding the astonishing number of cubic feet of timber collected here in so short a time, greater deposits have been in progress at the extremity of the delta in the Bay of Mexico. “Unfortunately for the navigation of the Mississippi,” observes Captain Hall, “some of the largest trunks, after being cast down from the position on which they grew, get their roots entangled with the bottom of the river, where they remain anchored, as it were, in the mud. The force of the current naturally gives their tops a tendency downwards, and, by its flowing past, soon strips them of their leaves and branches. These fixtures, called snags or planters, are extremely dangerous to the steam-vessels proceeding up the stream, in which they lie like a lance in rest, concealed beneath the water, with their sharp ends pointed directly against the bow of the vessels coming up. For the most part, these formidable snags remain so still, that they can be detected only by a slight ripple above them, not perceptible to inexperienced eyes. Sometimes, however, they vibrate up and down, alternately showing their heads above the surface and bathing them beneath it.”* So imminent is the danger caused by these obstructions, that almost all the boats on the

* Travels in North America, vol. iii, p. 362.

Mississippi are constructed on a particular plan, to guard against fatal accidents.*

The prodigious quantity of wood annually drifted down by the Mississippi and its tributaries, is a subject of geological interest, not merely as illustrating the manner in which abundance of vegetable matter becomes, in the ordinary course of Nature, imbedded in submarine and estuary deposits, but as attesting the constant destruction of soil and transportation of matter to lower levels by the tendency of rivers to shift their courses. Each of these trees must have required many years, some of them many centuries, to attain their full size : the soil, therefore, whereon they grew, after remaining undisturbed for long periods, is ultimately torn up and swept away. Yet, notwithstanding this incessant destruction of land and uprooting of trees, the region which yields this never-failing supply of drift wood is densely clothed with noble forests, and is almost unrivalled in its power of supporting animal and vegetable life.

Innumerable herds of wild deer and bisons feed on the luxurious pastures of the plains. The jaguar, the wolf, and the fox, are amongst the beasts of prey. The waters teem with alligators and tortoises, and their surface is covered with millions of migratory waterfowl, which perform their annual voyage between the Canadian lakes and the shores of the Mexican Gulf.

* "The boats are fitted," says Captain Hall, "with what is called a snag-chamber; — a partition, formed of stout planks, which is caulked, and made so effectually water-tight, that the foremost end of the vessel is cut off as entirely from the rest of the hold as if it belonged to another boat. If the steam-vessel happen to run against a snag, and that a hole is made in her bow, under the surface, this chamber merely fills with water." *Travels in North America*, vol. iii. p. 363.

The power of man begins to be sensibly felt, and the wilderness to be replaced by towns, orchards, and gardens. The gilded steam-boat, like a moving city, now stems the current with a steady pace — now shoots rapidly down the descending stream through the solitudes of the forests and prairies. Already does the flourishing population of the great valley exceed that of the thirteen United States when first they declared their independence, and, after a sanguinary struggle, were severed from the parent country.* Such is the state of a continent where rocks and trees are hurried annually, by a thousand torrents, from the mountains to the plains, and where sand and finer matter are swept down by a vast current to the sea, together with the wreck of countless forests and the bones of animals which perish in the inundations. When these materials reach the Gulf, they do not render the waters unfit for aquatic animals; but, on the contrary, the ocean here swarms with life, as it generally does where the influx of a great river furnishes a copious supply of organic and mineral matter. Yet many geologists, when they behold the spoils of the land heaped in successive strata, and blended confusedly with the remains of fishes, or interspersed with broken shells and corals, imagine that they are viewing the signs of a turbulent instead of a tranquil and settled state of the planet. They read in such phenomena the proof of chaotic disorder, and reiterated catastrophes, instead of indications of a surface as habitable as the most delicious and fertile districts now tenanted by man. They are not content with disregarding the analogy of the present course of Nature, when they

* Flint's Geography, vol. i.

speculate on the revolutions of past times, but they often draw conclusions, concerning the former state of things, directly the reverse of those to which a fair induction from facts would infallibly lead them.

Formation of lakes in Louisiana. — Another striking feature in the basin of the Mississippi, illustrative of the changes now in progress, is the formation by natural causes of great lakes, and the drainage of others. These are especially frequent in the basin of the Red River in Louisiana, where the largest of them, called Bistineau, is more than *thirty miles* long, and has a medium depth of from *fifteen to twenty* feet. In the deepest parts are seen numerous cypress trees, of all sizes, now dead, and most of them with their tops broken by the wind, yet standing erect under water. This tree resists the action of air and water longer than any other, and, if not submerged throughout the whole year, will retain life for an extraordinary period.* Lake Bistineau, as well as Black Lake, Cado Lake, Spanish Lake, Natchitoches Lake, and many others, have been formed, according to Darby, by the gradual elevation of the bed of Red River, in which the alluvial accumulations have been so great as to raise its channel, and cause its waters, during the flood season, to flow up the mouths of many tributaries, and to convert parts of their courses into lakes. In the autumn, when the level of Red River is again depressed, the waters rush back again, and some lakes become grassy meadows, with streams meandering

* Captains Clark and Lewis found a forest of pines standing erect under water in the body of the Columbia River in North America, which, they supposed, from the appearance of the trees, to have been only submerged about twenty years. — Vol. ii. p. 241.

through them.* Thus, there is a periodical flux and reflux between Red River and some of these basins, which are merely reservoirs, alternately emptied and filled like our tide estuaries — with this difference, that in the one case the land is submerged for several months continuously, and in the other, twice in every twenty-four hours. It has happened, in several cases, that a bar has been thrown by Red River across some of the openings of these channels, and then the lakes become, like Bistineau, constant repositories of water. But even in these cases, their level is liable to annual elevation and depression, because the flood of the main river, when at its height, passes over the bar; just as, where sand hills close the entrance of an estuary on the Norfolk or Suffolk coast, the sea, during some high tide or storm, has often breached the barrier and inundated again the interior.

Earthquakes in basin of Mississippi. — The frequent fluctuations in river courses, in various parts of the basin of the Mississippi, are partly, perhaps, to be ascribed to the co-operation of subterranean movements, which alter from time to time the relative levels of various parts of the surface. So late as the year 1812, the whole valley from the mouth of the Ohio to that of the St. Francis, including a tract three hundred miles in length, and exceeding in area the whole basin of the Thames, was convulsed to such a degree, as to create new islands in the river, and lakes in the alluvial plain, some of which were *twenty miles in extent*. We shall allude to this event, by which New Madrid was in great part destroyed, when we treat of earthquakes; but may state here, that it happened exactly at the

* Darby's Louisiana, p. 33.

same time as the fatal convulsions in the district of Caraccas ; and the country shaken was nearly five degrees of latitude farther removed from the great centre of volcanic disturbance, than the basin of the Red River, to which we before alluded.*

When countries are liable to be so extensively and permanently affected by earthquakes, speculations concerning changes in their hydrographical features must not be made without regard to the igneous as well as the aqueous causes of change. It is scarcely necessary to observe, that the inequalities produced even by one shock, might render the study of the alluvial plain of the Mississippi, at some future period, most perplexing to a geologist who should reason on the distribution of transported materials, without being aware that the configuration of the country had varied materially during the time when the excavating or removing power of the river was greatest.

FLOODS, BURSTING OF LAKES, ETC.

The power which running water may exert, in the lapse of ages, in widening and deepening a valley, does not so much depend on the volume and velocity of the stream usually flowing in it, as on the number and magnitude of the obstructions which have, at different periods, opposed its free passage. If a torrent, however small, be effectually dammed up, the size of the

* Darby mentions beds of marine shells on the banks of Red River, which seem to indicate that Lower Louisiana is of recent formation : its elevation, perhaps, above the sea, may have been due to the same series of earthquakes which continues to agitate equatorial America.

valley above the barrier, and its declivity below, and not the dimensions of the torrent, will determine the violence of the débâcle. The most universal source of local deluges are land-slips, slides, or avalanches, as they are sometimes called, when great masses of rock and soil, or sometimes ice and snow, are precipitated into the bed of a river, the boundary cliffs of which have been thrown down by the shock of an earthquake, or undermined by springs or other causes. Volumes might be filled with the enumeration of all the instances which are on record of these terrific catastrophes : I shall therefore select a few examples of recent occurrence, the facts of which are well authenticated.

Floods caused by land-slips, 1826. — Two dry seasons in the White Mountains, in New Hampshire, were followed by heavy rains on the 28th August, 1826, when from the steep and lofty declivities which rise abruptly on both sides of the river Saco, innumerable rocks and stones, many of sufficient size to fill a common apartment, were detached, and in their descent swept down before them, in one promiscuous and frightful ruin, forests, shrubs, and the earth which sustained them. No tradition existed of any similar slides at former times, and the growth of the forest on the flanks of the hills clearly showed that for a long interval nothing similar had occurred. One of these moving masses was afterwards found to have slid three miles, with an average breadth of a quarter of a mile. The natural excavations commenced generally in a trench a few yards in depth and a few rods in width, and descended the mountains, widening and deepening till they became vast chasms. At the base of these hollow ravines was seen a wide and deep mass of ruins, consisting of transported earth, gravel, rocks, and trees.

Forests of spruce-fir and hemlock were prostrated with as much ease as if they had been fields of grain ; for, where they disputed the ground, the torrent of mud and rock accumulated behind till it gathered sufficient force to burst the temporary barrier.

The valleys of the Amonoosuck and Saco presented, for many miles, an uninterrupted scene of desolation ; all the bridges being carried away, as well as those over their tributary streams. In some places, the road was excavated to the depth of from fifteen to twenty feet ; in others, it was covered with earth, rocks, and trees, to as great a height. The water flowed for many weeks after the flood, as densely charged with earth as it could be without being changed into mud, and marks were seen in various localities of its having risen on either side of the valley to more than twenty-five feet above its ordinary level. Many sheep and cattle were swept away, and the Willey family, nine in number, who in alarm had deserted their house, were destroyed on the banks of the Saco ; seven of their mangled bodies were afterwards found near the river, buried beneath drift wood and mountain ruins.* We may remind the geologist that the lower alluvial plains are most exposed to such violent floods, and are at the same time best fitted for the sustenance of herbivorous animals. If, therefore, any organic remains are found amidst the superficial heaps of transported matter, resulting from those catastrophes, at whatever periods they may have happened, and whatever may have been the former configuration and relative levels of the country, we may expect the imbedded fossil

* Silliman's Journal of Science, vol. xv. No. 2. p. 216. Jan. 1829.

relics to be principally referrible to this class of mammalia.

But these catastrophes are insignificant, when compared to those which are occasioned by earthquakes, when the boundary hills, for miles in length, are thrown down into the hollow of a valley. I shall have opportunities of alluding to inundations of this kind when treating of earthquakes, and shall content myself at present with selecting an example, of modern date, of a flood caused by the bursting of a temporary lake; the facts having been described, with more than usual accuracy, by scientific observers.

Flood in the Valley of Bagnes, 1818.—The valley of Bagnes is one of the largest of the lateral embranchments of the main valley of the Rhone, above the Lake of Geneva. Its upper portion was, in 1818, converted into a lake by the damming up of a narrow pass, by avalanches of snow and ice, precipitated from an elevated glacier into the bed of the river Dranse. In the winter season, during continued frost, scarcely any water flows in the bed of this river to preserve an open channel, so that the ice-barrier remained entire until the melting of the snows in spring, when a lake was formed above, about half a league in length, which finally attained in some parts a depth of about two hundred feet, and a width of about seven hundred feet. To prevent or lessen the mischief apprehended from the sudden bursting of the barrier, an artificial gallery, seven hundred feet in length, was cut through the ice, before the waters had risen to a great height. When at length they accumulated and flowed through this tunnel, they dissolved the ice, and thus deepened their channel, until nearly half of the whole contents of the lake were slowly

drained off. But, at length, on the approach of the hot season, the central portion of the remaining mass of ice gave way with a tremendous crash, and the residue of the lake was emptied in half an hour. In the course of its descent, the waters encountered several narrow gorges, and at each of these they rose to a great height, and then burst with new violence into the next basin, sweeping along rocks, forests, houses, bridges, and cultivated land. For the greater part of its course the flood resembled a moving mass of rock and mud, rather than of water. Some fragments of granitic rocks, of enormous magnitude, and which, from their dimensions, might be compared without exaggeration to houses, were torn out of a more ancient alluvion, and borne down for a quarter of a mile. The velocity of the water, in the first part of its course, was thirty-three feet per second, which diminished to six feet before it reached the Lake of Geneva, where it arrived in six hours and a half, the distance being forty-five miles.*

This flood left behind it, on the plains of Martigny, thousands of trees torn up by the roots, together with the ruins of buildings. Some of the houses in that town were filled with mud up to the second story. After expanding in the plain of Martigny, it entered the Rhone and did no further damage; but some bodies of men, who had been drowned above Martigny, were afterwards found, at the distance of about thirty miles, floating on the farther side of the Lake of Geneva, near Vevey.

The waters, on escaping from the lake, intermixed

* See an account of the inundation of the Val de Bagnes, in 1818, in *Ed. Phil. Journ.* vol. i. p. 187. Drawn up from the *Memoir of M. Escher*, with a section, &c.

with mud and rock, swept along, for the first four miles, at the rate of above twenty miles an hour; and M. Escher, the engineer, calculated that the flood furnished 300,000 cubic feet of water every second,—an efflux which is five times greater than that of the Rhine below Basle. Now, if part of the lake had not been gradually drained off, the flood would have been nearly double, approaching in volume to some of the largest rivers in Europe. It is evident, therefore, that, when we are speculating on the excavating force which a river may have exerted in any particular valley, the most important question is, not the volume of the existing stream, nor the present levels of its channel, nor even the nature of the rocks, but the probability of a succession of floods, at some period since the time when the valley may have been first elevated above the sea.

For several months after the débâcle of 1818, the Dranse, having no settled channel, shifted its position continually from one side to the other of the valley, carrying away newly-erected bridges, undermining houses, and continuing to be charged with as large a quantity of earthy matter as the fluid could hold in suspension. I visited this valley four months after the flood, and was witness to the sweeping away of a bridge, and the undermining of part of a house. The greater part of the ice-barrier was then standing, presenting vertical cliffs 150 feet high, like ravines in the lava-currents of Etna or Auvergne, where they are intersected by rivers.

Inundations, precisely similar, are recorded to have occurred at former periods in this district, and from the same cause. In 1595, for example, a lake burst, and the waters, descending with irresistible fury, de-

stroyed the town of Martigny, where from sixty to eighty persons perished. In a similar flood, fifty years before, 140 persons were drowned.

Flood at Tivoli, 1826.—I shall conclude with one more example, derived from a land of classic recollections, the ancient Tibur, and which, like all the other inundations above alluded to, occurred within the present century. The younger Pliny, it will be remembered, describes a flood on the Anio, which destroyed woods, rocks, and houses, with the most sumptuous villas and works of art.* For four or five centuries consecutively, this headlong stream, as Horace truly called it, has often remained within its bounds, and then, after so long an interval of rest, has at different periods inundated its banks again, and widened its channel. The last of these catastrophes happened 15th Nov. 1826, after heavy rains, such as produced the floods before alluded to in Scotland. The waters appear also to have been impeded by an artificial dike, by which they were separated into two parts, a short distance above Tivoli. They broke through this dike, and, leaving the left trench dry, precipitated themselves, with their whole weight, on the right side. Here they undermined, in the course of a few hours, a high cliff, and widened the river's channel about fifteen paces. On this height stood the church of St. Lucia, and about thirty-six houses of the town of Tivoli, which were all carried away, presenting, as they sank into the roaring flood, a terrific scene of destruction to the spectators on the opposite bank. As the foundations were gradually removed, each building, some of them edifices of considerable

* Lib. viii. Epist. 17.

height, was first traversed with numerous rents, which soon widened into large fissures, until at length the roofs fell in with a crash, and then the walls sank into the river, and were hurled down the cataract below.*

The destroying agency of the flood came within two hundred yards of the precipice on which the beautiful temple of Vesta stands; but fortunately this precious relic of antiquity was spared, while the wreck of modern structures was hurled down the abyss. Vesta, it will be remembered, in the heathen mythology, personified the stability of the earth; and when the Samian astronomer, Aristarchus, first taught that the earth revolved on its axis, and round the sun, he was publicly accused of impiety, "for moving the everlasting Vesta from her place." Playfair† observed that when Hutton ascribed instability to the earth's surface, and represented the continents which we inhabit as the theatre of incessant change and movement, his antagonists, who regarded them as unalterable, assailed him, in a similar manner, with accusations founded on religious prejudices. We might appeal to the excavating power of the Anio as corroborative of one of the most controverted parts of the Huttonian theory; and, if the days of omens had not gone by, the geologists who now worship Vesta might regard the late catastrophe as portentous. We may, at least, recommend the modern votaries of the goddess to lose no time in making a pilgrimage to her shrine, for the next flood may not respect the temple.

* When at Tivoli, in 1829, I received this account from eye-witnesses of the event.

† Illustr. of Hutt. Theory, § 3. p. 147.

CHAPTER III.

PHENOMENA OF SPRINGS.

Origin of Springs — Bored wells — Distinct causes by which mineral and thermal waters may be raised to the surface — Their connexion with volcanic agency — Calcareous springs — Travertin of the Elsa — Baths of San Vignone and of San Filippo, near Radicofani — Spheroidal structure in travertin, as in English magnesian limestone — Bulicami of Viterbo — Lake of the Solfatara, near Rome — Travertin at Cascade of Tivoli — Gypseous, Siliceous, and Ferruginous Springs — Brine Springs — Carbonated Springs — Disintegration of granite in Auvergne — Petroleum Springs — Pitch Lake of Trinidad.

Origin of springs. — THE action of running water on the land having been considered, we may next turn our attention to what may be termed “the subterranean drainage,” or the phenomena of springs. Every one is familiar with the fact, that certain porous soils, such as loose sand and gravel, absorb water with rapidity; and that the ground composed of them soon dries up after heavy showers.* If a well be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching the lower parts of the formation, where it rests on some impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same manner as we see the salt water flow into, and fill, any hollow which we dig in the sands of the shore at low tide.

The facility with which water can percolate loose and gravelly soils is clearly illustrated by the effect of the tides in the Thames, between Richmond and London. The river, in this part of its course, flows through a bed of gravel overlying clay, and the porous superstratum is alternately saturated by the water of the Thames as the tide rises, and then drained again to the distance of several hundred feet from the banks when the tide falls, so that the wells in this tract regularly ebb and flow.

If the transmission of water through a porous medium be so rapid, we cannot be surprised that springs should be thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, or other permeable substances, while the subjacent are composed of clay or other retentive soils. The only difficulty, indeed, is, to explain why the water does not ooze out every where along the line of junction of the two formations, so as to form one continuous land-soak, instead of a few springs only, and these far distant from each other. The principal cause of this concentration of the waters at a few points is, first, the frequency of rents and fissures, which act as natural drains; secondly, the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels.

That the generality of springs owe their supply to the atmosphere is evident from this, that they become languid, or entirely cease to flow, after long droughts, and are again replenished after a continuance of rain. For the constancy and uniformity of their volume they are probably indebted to the great extent of the

subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in every great lake, which is not sensibly affected in its level by sudden showers, but only slightly raised; so that its channel of efflux, instead of being swollen suddenly like the bed of a torrent, is enabled to carry off the surplus water more gradually.

Much light has been thrown, of late years, on the theory of springs, by the boring of what are called by the French "Artesian wells," because the method has long been known and practised in Artois; and it is now demonstrated that there are sheets of fresh water, and, in some places, currents at various depths in the earth. The instrument employed in excavating these wells is a large auger, and the cavity bored is usually from three to four inches in diameter. If a hard rock is met with, it is first triturated by an iron rod, and the materials, being thus reduced to small fragments or powder, are readily extracted. To hinder the sides of the well from falling in, as also to prevent the spreading of the ascending water in the surrounding soil, a jointed pipe is introduced, formed of wood in Artois, but in other countries more commonly of metal. It frequently happens that, after passing through hundreds of feet of retentive soils, a water-bearing stratum is at length pierced, when the fluid immediately ascends to the surface and flows over. The first rush of the water up the tube is often violent, so that for a time the water plays like a fountain, and then, sinking, continues to flow over tranquilly, or sometimes remains stationary at a certain depth below the orifice of the well. This

spouting of the water in the first instance is probably owing to the disengagement of air and carbonic acid gas, for both of these have been seen to bubble up with the water.*

At Sheerness, at the mouth of the Thames, a well was bored on a low tongue of land near the sea, through 300 feet of the blue clay of London, below which a bed of sand and pebbles was entered, belonging, doubtless, to the plastic clay formation: when this stratum was pierced, the water burst up with impetuosity, and filled the well. By another perforation at the same place, the water was found at the depth of 328 feet, below the clay; it first rose rapidly to the height of 189 feet, and then, in the course of a few hours, ascended to an elevation of eight feet above the level of the ground. In 1824, a well was dug at Fulham, near the Thames, at the Bishop of London's, to the depth of 317 feet, which, after traversing the tertiary strata, was continued through 67 feet of chalk. The water immediately rose to the surface, and the discharge was above 50 gallons per minute. In the garden of the Horticultural Society at Chiswick, chalk was also reached at a depth of 329 feet, from which the water rose to the surface. At the Duke of Northumberland's, above Chiswick, the borings were carried to the extraordinary depth of 620 feet into the chalk, when a considerable volume of water was obtained, which rose four feet above the surface of the ground. In a well of Mr. Brooks, at Hammersmith, the rush of water from a depth of 360 feet was so great, as to inundate several buildings and do considerable damage; and at Tooting,

* Consult Héricart de Thury's work on "Puits Forés."

a sufficient stream was obtained to turn a wheel, and raise the water to the upper stories of the houses.* In the last of three wells bored through the chalk, at Tours, to the depth of several hundred feet, the water rose thirty-two feet above the level of the soil, and the discharge amounted to three hundred cubic yards of water every twenty-four hours.†

Excavations have been made in the same way to the depth of eight hundred, and even twelve hundred feet in France (the latter at Toulouse), and without success.‡ A similar failure was experienced in 1830, in boring at Calcutta, to the depth of more than 150 feet, through the alluvial clay and sands of Bengal. Mr. Briggs, the British consul in Egypt, obtained water between Cairo and Suez, in a calcareous sand, at the depth of thirty feet; but it did not rise in the well.§ The geological structure of the Sahara is supposed, by M. Rozet, to favour the prospect of a supply of water from artesian wells, as the parched sands on the outskirts of the desert rest on a substratum of argillaceous marl.||

The rise and overflow of the water in these wells is generally referred, and apparently with reason, to the same principle as the play of an artificial fountain.

* Héricart de Thury, p. 49.

† Bull. de la Soc. Géol. de France, tom. iii. p. 194.

‡ Id. tom. ii. p. 272.

§ Boué, Résumé des Prog. de la Géol. en 1832, p. 184.

|| Bull. de la Soc. Géol. de France, tom. ii. p. 364.

Let the porous stratum, or set of strata *a a*, rest on the impermeable rock *d*, and be covered by another mass of an impermeable nature. The whole mass *a a* may easily, in such a position, become saturated with water, which may descend from its higher and exposed parts—a hilly region to which clouds are attracted, and where rain falls in abundance. Suppose that at some point, as at *b*, an opening be made which gives a free passage upwards to the waters confined in *a a* at so low a level that they are subjected to the pressure of a considerable column of water collected in the more elevated portion of the same stratum. The water will then rush out, just as the liquid from a large barrel which is tapped, and it will rise to a height corresponding to the level of its point of departure, or, rather, to a height, which balances the pressure previously exerted by the confined waters against the roof and sides of the stratum or reservoir *a a*. In like manner, if there happen to be a natural fissure *c*, a spring will be produced at the surface on precisely the same principle.

Among the causes of the failure of artesian wells, we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for, when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands, to some trough in an opposite direction; as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs.

The mere distance of hills or mountains need not discourage us from making trials ; for the waters which fall on these higher lands readily penetrate to great depths through highly inclined or vertical strata, or through the fissures of shattered rocks, and after flowing for a great distance, must often reascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. It should be remembered, that the course of waters flowing under ground bears but a remote resemblance to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea ; whereas, in the other, the water may at one time sink far below the level of the ocean, and afterwards rise again high above it.

Among other curious facts ascertained by aid of the borer, it is proved that in strata of different ages and compositions, there are often open passages by which the subterranean waters circulate. Thus, at St. Ouen, in France, five distinct sheets of water were intersected in a well, and from each of these a supply obtained. In the third water-bearing stratum, at the depth of 150 feet, a cavity was found in which the borer fell suddenly about a foot, and thence the water ascended in great volume.* The same falling of the instrument, as in a hollow space, has been remarked in England and other countries. At Tours, in 1830, a well was perforated quite through the chalk, when the water suddenly brought up, from a depth of 364 feet, a great quantity of fine sand, with much vegetable

* H. de Thury, p. 295.

matter and shells. Branches of a thorn several inches long, much blackened by their stay in the water, were recognized, as also the stems of marsh plants, and some of their roots, which were still white, together with the seeds of the same, in a state of preservation which showed that they had not remained more than three or four months in the water. Among the seeds were those of the marsh-plant *Galium uliginosum*; and among the shells, a freshwater species (*Planorbis marginatus*), and some land species, as *Helix rotundata* and *H. striata*. M. Dujardin, who, with others, observed this phenomenon, supposes that the waters had flowed from some valleys of Auvergne or the Vivarais since the preceding autumn.*

An analogous phenomenon is recorded at Riemke, near Bochum in Westphalia, where the water of an artesian well brought up, from a depth of 156 feet, several small fish, three or four inches long, the nearest streams in the country being at the distance of some leagues.†

In both cases it is evident that water had penetrated to great depths, not simply by filtering through a porous mass, for then it would have left behind the shells, fish, and fragments of plants, but by flowing through some open channels in the earth. Such examples may suggest the idea that the leaky beds of rivers are often the feeders of springs.

MINERAL AND THERMAL SPRINGS.

Almost all springs, even those which we consider the purest, are impregnated with some foreign ingredients,

* Bull. de la Soc. Géol. de France, tom. i. p. 95.

† Id. p. 248.

which, being in a state of chemical solution, are so intimately blended with the water, as not to affect its clearness, while they render it, in general, more agreeable to our taste, and more nutritious than simple rain-water. But the springs called mineral contain an unusual abundance of earthy matter in solution, and the substances with which they are impregnated correspond remarkably with those evolved in a gaseous form by volcanos. Many of these springs are thermal, and they rise up through all kinds of rock; as, for example, through granite, gneiss, limestone, or lava, but are most frequent in volcanic regions, or where violent earthquakes have occurred at eras comparatively modern.

The water given out by hot springs is generally more voluminous and less variable in quantity at different seasons than that proceeding from any others. In many volcanic regions, jets of steam, called by the Italians "stufas," issue from fissures, at a temperature high above the boiling point, as in the neighbourhood of Naples, and in the Lipari Isles, and are disengaged unceasingly for ages. Now, if such columns of steam, which are often mixed with other gases, should be condensed before reaching the surface, by coming in contact with strata filled with cold water, they may give rise to thermal and mineral springs of every degree of temperature. It is, indeed, by this means only, and not by hydrostatic pressure, that we can account for the rise of such bodies of water from great depths; nor can we hesitate to admit the adequacy of the cause, if we suppose the expansion of the same elastic fluids to be sufficient to raise columns of lava to the lofty summits of volcanic mountains. Several gases, the carbonic acid in particular, are disengaged in a free state from the soil

in many districts, especially in the regions of active or extinct volcanos: and the same are found more or less intimately combined with the waters of all mineral springs, both cold and thermal. Dr. Daubeny and other writers have remarked, not only that these springs are most abundant in volcanic regions, but that when remote from them, their site usually coincides with the position of some great derangement in the strata; a fault, for example, or great fissure, indicating that a channel of communication has been opened with the interior of the earth at some former period of local convulsion.

The small area of volcanic regions may appear, at first view, an objection to this theory, but not so when we include earthquakes among the effects of igneous agency. A large proportion of the land hitherto explored by geologists, can be shown to have been rent or shaken by subterranean movements since the oldest tertiary strata were formed. It will also be seen, in the sequel, that new springs have burst out, and others have had the volume of their waters augmented, and their temperature suddenly raised after earthquakes; so that the description of these springs might almost with equal propriety have been given under the head of "igneous causes," as they are agents of a mixed nature, being at once igneous and aqueous.

But how, it will be asked, can the regions of volcanic heat send forth such inexhaustible supplies of water? The difficulty of solving this problem would, in truth, be insurmountable, if we believed that all the atmospheric waters found their way into the basin of the ocean; but in boring near the shore, we often meet with streams of fresh water at the depth of several hundred feet below the sea level; and these probably

descend, in many cases, far beneath the bottom of the sea, when not artificially intercepted in their course. Yet, how much greater may be the quantity of salt water which sinks beneath the floor of the ocean, through the porous strata of which it is often composed, or through fissures rent in it by earthquakes! After penetrating to a considerable depth, this water may encounter a heat of sufficient intensity to convert it into vapour, even under the high pressure to which it would then be subjected. This heat would probably be nearest the surface in volcanic countries, and farthest from it in those districts which have been longest free from eruptions or earthquakes; but to pursue this inquiry farther would lead us to anticipate many topics belonging to another division of our subject.

It would follow from the views above explained, that there must be a two-fold circulation of terrestrial waters; one caused by solar heat, and the other by heat generated in the interior of our planet. We know that the land would be unfit for vegetation, if deprived of the waters raised into the atmosphere by the sun; but it is also true that mineral springs are powerful instruments in rendering the surface subservient to the support of animal and vegetable life. Their heat promotes the development of the aquatic tribes in many parts of the ocean, and the substances which they carry up from the bowels of the earth to the habitable surface, are of a nature and in a form which adapts them peculiarly for the nutrition of animals and plants.

As these springs derive their chief importance to the geologist from the quantity and quality of the earthy materials which, like volcanos, they convey

from below upwards, they may properly be considered in reference to the ingredients with which they are impregnated. These consist of almost all known substances; but the most predominant are, carbonate of lime, carbonic and sulphuric acids, iron, silica, magnesia, alumine, and salt, besides petroleum, or liquid bitumen, and its various modifications, such as mineral pitch, naptha, and asphaltum.

Calcareous springs.—Our first attention is naturally directed to springs which are highly charged with calcareous matter; for these produce a variety of phenomena of much interest to the geologist. It is well known that rain-water has the property of dissolving the calcareous rocks over which it flows, and by these means, matter is often supplied for the earthy secretions of testacea, and for the growth of certain plants on which they feed, in the smallest ponds and rivulets. But many springs hold so much carbonic acid in solution, that they are enabled to dissolve a much larger quantity of calcareous matter than rain-water; and when the acid is dissipated in the atmosphere, the mineral ingredients are thrown down, in the form of tufa or travertin.

Auvergne. — Calcareous springs, although most abundant in limestone districts, are by no means confined to them, but flow out indiscriminately from all rock formations. In Central France, a district where the primary rocks are unusually destitute of limestone, springs copiously charged with carbonate of lime rise up through the granite and gneiss. Some of these are thermal, and probably derive their origin from the deep source of volcanic heat, once so active in that region. One of these springs, at the northern base of the hill upon which Clermont is built, issues from

volcanic peperino, which rests on granite. It has formed, by its incrustations, an elevated mound of travertin, or white concretionary limestone, 240 feet in length, and, at its termination, sixteen feet high and twelve wide. Another incrusting spring in the same department, situated at Chaluzet, near Pont Gibaud, rises in a gneiss country, at the foot of a regular volcanic cone, at least twenty miles from any calcareous rock. Some masses of tufaceous deposit, produced by this spring, have an oolitic texture.

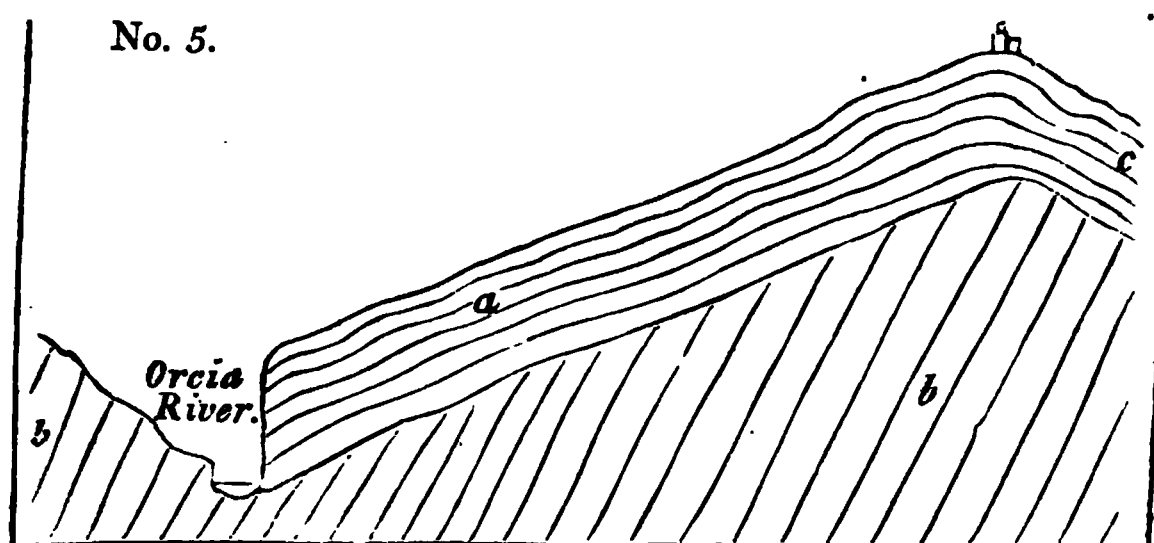
Valley of the Elsa.—If we pass from the volcanic district of France to that which skirts the Apennines in the Italian peninsula, we meet with innumerable springs, which have precipitated so much calcareous matter, that the whole ground in some parts of Tuscany is coated over with travertin, and sounds hollow beneath the foot.

In other places in the same country, compact rocks are seen descending the slanting sides of hills, very much in the manner of lava currents, except that they are of a white colour, and terminate abruptly when they reach the course of a river. These consist of the calcareous precipitate of springs, some of them still flowing, while others have disappeared or changed their position. Such masses are frequent on the slope of the hills which bound the valley of the Elsa, one of the tributaries of the Arno, which flows near Colle, through a valley several hundred feet deep, shaped out of a lacustrine formation, containing fossil shells of existing species. The travertin is unconformable to the lacustrine beds, and its inclination accords with the slope of the sides of the valley.

One of the finest examples which I saw, was at the Molino delle Caldane, near Colle.

The Sena, and several other small rivulets which feed the Elsa, have the property of lapidifying wood and herbs; and, in the bed of the Elsa itself, aquatic plants, such as Charæ, which absorb large quantities of carbonate of lime, are very abundant. Carbonic acid is also seen in the same valley, bubbling up from many springs, where no precipitate of tufa is observable. Targioni, who in his travels has mentioned a great number of mineral waters in Tuscany, found no difference between the deposits of cold and thermal springs. They issue sometimes from the older Apennine limestone, shale, and sandstone, while, in other places, they flow from more modern deposits; but even in the latter case, their source may probably be in or below the older series of strata.

Baths of San Vignone. — Those persons who have merely seen the action of petrifying waters in our own country, will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the active centres of volcanic disturbance. One of the most striking examples of the rapid precipitation of carbonate of lime from thermal waters occurs in the hill of San Vignone in Tuscany, at a short distance from Radicofani, and only a few hundred yards from the high road between Sienna and Rome. The spring issues from near the summit of a rocky hill, about 100 feet in height. The top of the hill is flat, and stretches in a gently-inclined platform to the foot of Mount Amiata, a lofty eminence, which consists in great part of volcanic products. The fundamental rock, from which the spring issues, is a black slate, with serpentine (*b b*, diagram 5.), belonging to the older Apennine formation. The water is hot, has a strong taste, and,

Baths of San Vignone*Section of Travertin, San Vignone.*

when not in very small quantity, is of a bright green colour. So rapid is the deposition near the source, that in the bottom of a conduit-pipe for carrying off the water to the baths, and which is inclined at an angle of 30° , half a foot of solid travertin is formed every year. A more compact rock is produced where the water flows slowly, and the precipitation in winter, when there is least evaporation, is said to be more solid, but less in quantity by one-fourth, than in summer. The rock is generally white; some parts of it are compact, and ring to the hammer; others are cellular, and with such cavities as are seen in the carious part of bone or the siliceous millstone of the Paris basin. A portion of it also below the village consists of long vegetable tubes. Sometimes the travertin assumes precisely the botryoidal and mammillary forms, common to similar deposits in Auvergne, of a much older date, hereafter to be mentioned; and, like them, it often scales off in thin, slightly-undulating layers.

A large mass of travertin (c, diagram 5.) descends the hill from the point where the spring issues, and reaches to the distance of about half a mile east of San

Vignone. The beds take the slope of the hill at about an angle of 6° , and the planes of stratification are perfectly parallel. One stratum, composed of many layers, is of a compact nature, and fifteen feet thick ; it serves as an excellent building stone, and a mass of fifteen feet in length was, in 1828, cut out for the new bridge over the Orcia. Another branch of it (*a*, diagram 5.) descends to the west, for 250 feet in length, of varying thickness, but sometimes 200 feet deep : it is then cut off by the small river Orcia, precisely as some glaciers in Switzerland descend into a valley till their progress is suddenly arrested by a transverse stream of water.

The abrupt termination of the mass of rock at the river, when its thickness is undiminished, clearly shows that it would proceed much farther if not arrested by the stream, over which it impends slightly. But it cannot encroach upon the channel of the Orcia, being constantly undermined, so that its solid fragments are seen strewn amongst the alluvial gravel. However enormous, therefore, the mass of solid rock may appear which has been given out by this single spring, we may feel assured that it is insignificant in volume when compared to that which has been carried to the sea since the time when it began to flow. What may have been the length of that period of time, we have no data for conjecturing. In quarrying the travertin, Roman tiles have been sometimes found at the depth of five or six feet.

Baths of San Filippo. — On another hill, not many miles from that last mentioned, and also connected with Mount Amiata, the summit of which is about three miles distant, are the celebrated baths of San Filippo. The subjacent rocks consist of alternations of black slate, limestone, and serpentine, of highly

inclined strata, belonging to the Apennine formation, and, as at San Vignone, near the boundary of a tertiary basin of marine origin, consisting chiefly of blue argillaceous marl. There are three warm springs here, containing carbonate and sulphate of lime, and sulphate of magnesia. The water which supplies the bath falls into a pond, where it has been known to deposit a solid mass *thirty feet thick*, in about *twenty years*.* A manufactory of medallions in basso-relievo is carried on at these baths. The water is conducted by canals into several pits, in which it deposits travertin and crystals of sulphate of lime. After being thus freed from its grosser parts, it is conveyed by a tube to the summit of a small chamber, and made to fall through a space of ten or twelve feet. The current is broken in its descent by numerous crossed sticks, by which the spray is dispersed around upon certain moulds, which are rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould.† The geologist may derive from these experiments considerable light, in regard to the high inclination at which some semicrystalline precipitations can be formed; for some of the moulds are disposed almost perpendicularly, yet the deposition is nearly equal in all parts.

A hard stratum of stone about a foot in thickness, is obtained from the waters of San Filippo in four months; and, as the springs are powerful, and almost uniform in the quantity given out, we are at no loss to com-

* Dr. Grosse on the Baths of San Filippo. Ed. Phil. Journ. vol. ii. p. 292.

† Id. p. 297.

prehend the magnitude of the mass which descends the hill, which is a mile and a quarter in length and the third of a mile in breadth, in some places attaining a thickness of 250 feet at least. To what length it might have reached it is impossible to conjecture, as it is cut off, like the travertin of San Vignone, by a small stream, where it terminates abruptly. The remainder of the matter held in solution is carried on probably to the sea.

Spheroidal structure in travertin.—But what renders this recent calcareo-magnesian limestone of peculiar interest to the geologist, is the spheroidal form which it assumes, offering so striking an analogy, on the one hand, to the concentric structure displayed in the calcareous travertin of the cascade of Tivoli, and, on the other, to the spheroidal form of the English magnesian limestone of Sunderland. Between this latter and many of the appearances exhibited at San Filippo, and several other recent deposits of the same kind in Italy, I recognized every feature of resemblance; the same combination of concentric and radiated structure, with small undulations in each concentric ring, occasional interferences of one circle with another, and a small globular structure subordinate to the large spheroidal, with frequent examples of laminæ passing off from the external coating of a spheroid into layers parallel to the general plane of stratification. There are also cellular cavities and vacuities in the rock, constituting what has been termed a honeycombed texture. The lamination of some of the concentric masses of San Filippo is so minute, that sixty may be counted in the thickness of an inch. Yet, notwithstanding these marks of gradual and successive deposition, the symmetry and magnitude of many of the spheroidal forms

might convey the idea, that the whole was the result of chemical action, simultaneously operating on a great mass of matter.

The concretionary forms of our magnesian limestone have been supposed by some to have been superinduced after the component parts of the rock had been brought together in stratiform masses ; but a careful comparison of those older rocks with the numerous travertins now in progress of formation in Italy has led me to a different conclusion. Such a structure seems to be the result of gradual precipitation, and not of the subsequent rearrangement of the particles.* Each minute particle of foreign matter, a reed, or the fragment of a shell, forms a nucleus, around which accessions of new laminæ are formed, until spheroids and elongated cones, from a few inches to several feet in diameter, are produced ; for, as the precipitate is arranged by the force of chemical affinity, and not of gravity, the different layers continue of the same thickness, and preserve the original form of the nucleus.

* The structure of the English magnesian limestone has been accurately described, in an elaborate paper on that formation, by Professor Sedgwick. *Geol. Trans.* vol. 3. second series, part i. p. 37. Examples of almost all the modifications of concretionary arrangement, together with the brecciated and honeycombed structure to which he alludes, may be found either in the deposits of travertin springs in various parts of Italy, or in the subaqueous travertins of Auvergne and Sicily, — the former of lacustrine, the latter of submarine origin. After examining these more recent deposits, I visited Sunderland, and recognized a degree of identity in the various and complicated forms there assumed by the magnesian limestone, which satisfied me that the circumstances under which they were formed must have been strictly analogous to those under which the mineral springs of volcanic countries are now giving rise to calcareous and calcareo-siliceous rocks.

Bulicami of Viterbo.—I must not attempt to describe all the places in Italy where the constant formation of limestone may be seen, as on the Silaro, near Pæstum, on the Velino at Terni, and near the Bulicami, or hot baths in the vicinity of Viterbo. About a mile and a half north of the latter town, in the midst of a sterile plain of volcanic sand and ashes, a monticule is seen, about twenty feet high and five hundred yards in circumference, entirely composed of concretionary travertin. The laminæ are extremely thin, and their minute undulations are so arranged, that the whole mass has at once a concentric and radiated structure. This rock has been largely quarried for lime, and much of it appears to have been removed. It has evidently been formed gradually, like the conical mounds of the geysers in Iceland, by a small jet or fountain of calcareous water, which overflowed from the summit of the monticule. A spring of hot water still issues in the neighbourhood, which is conveyed to an open tank used as a bath, the bottom and sides of which, as well as the open conduit which conveys the water, are encrusted with travertin.

Campagna di Roma.—The country around Rome, like many parts of the Tuscan States already referred to, has been at some former period the site of numerous volcanic eruptions; and the springs are still copiously impregnated with lime, carbonic acid, and sulphuretted hydrogen. A hot spring has lately been discovered near Civita Vecchia, by Signor Riccioli, which deposits alternate beds of a yellowish travertin, and a white granular rock, not distinguishable, in hand specimens, either in grain, colour, or composition, from statuary marble. There is a passage between this and ordinary

travertin. The mass accumulated near the spring is in some places about six feet thick.*

Lake of the Solfatara.—In the Campagna, between Rome and Tivoli, is the lake of the Solfatara, called also Lago di Zolfo (lacus albula), into which flows continually a stream of tepid water, from a smaller lake situated a few yards above it. The water is a saturated solution of carbonic acid gas, which escapes from it in such quantities in some parts of its surface, that it has the appearance of being actually in ebullition. “I have found by experiment,” says Sir Humphry Davy, “that the water taken from the most tranquil part of the lake, even after being agitated and exposed to the air, contained in solution more than its own volume of carbonic acid gas, with a very small quantity of sulphuretted hydrogen. Its high temperature, which is pretty constant at 80° of Fahr., and the quantity of carbonic acid that it contains, render it peculiarly fitted to afford nourishment to vegetable life. The banks of travertin are every where covered with reeds, lichen, confervæ, and various kinds of aquatic vegetables; and at the same time that the process of vegetable life is going on, the crystallizations of the calcareous matter, which is every where deposited in consequence of the escape of carbonic acid, likewise proceed.—There is, I believe, no place in the world where there is a more striking example of the opposition or contrast of the laws of animate and inanimate

* I did not visit this spring myself, but Signor Riccioli, whose acquaintance with the geology of the environs of Rome is well known, favoured me with an inspection of a suite of specimens collected from the spot. Brocchi, a few years before his death, visited the locality in company with Signor Riccioli.

nature, of the forces of inorganic chemical affinity, and those of the powers of life."*

The same observer informs us, that he fixed a stick in a mass of travertin covered by the water in the month of May, and in April following he had some difficulty in breaking, with a sharp-pointed hammer, the mass which adhered to the stick, and which was several inches in thickness. The upper part was a mixture of light tufa and the leaves of *confervæ*: below this was a darker and more solid travertin, containing black and decomposed masses of *confervæ*; in the inferior part the travertin was more solid, and of a grey colour, but with cavities probably produced by the decomposition of vegetable matter.†

The stream which flows out of this lake fills a canal about nine feet broad and four deep, and is conspicuous in the landscape by a line of vapour which rises from it. It deposits tufa in this channel, and the Tiber probably receives from it, as well as from numerous other streams, much carbonate of lime in solution, which may contribute to the rapid growth of its delta. A large proportion of the most splendid edifices of ancient and modern Rome are built of travertin, derived from the quarries of Ponte Leucano, where there has evidently been a lake at a remote period, on the same plain as that already described. But the consideration of these would carry us beyond the times of history, and I shall conclude with one more example of the calcareous deposits of this neighbourhood,—those on the Anio.

Travertin of Tivoli.—The waters of the Anio

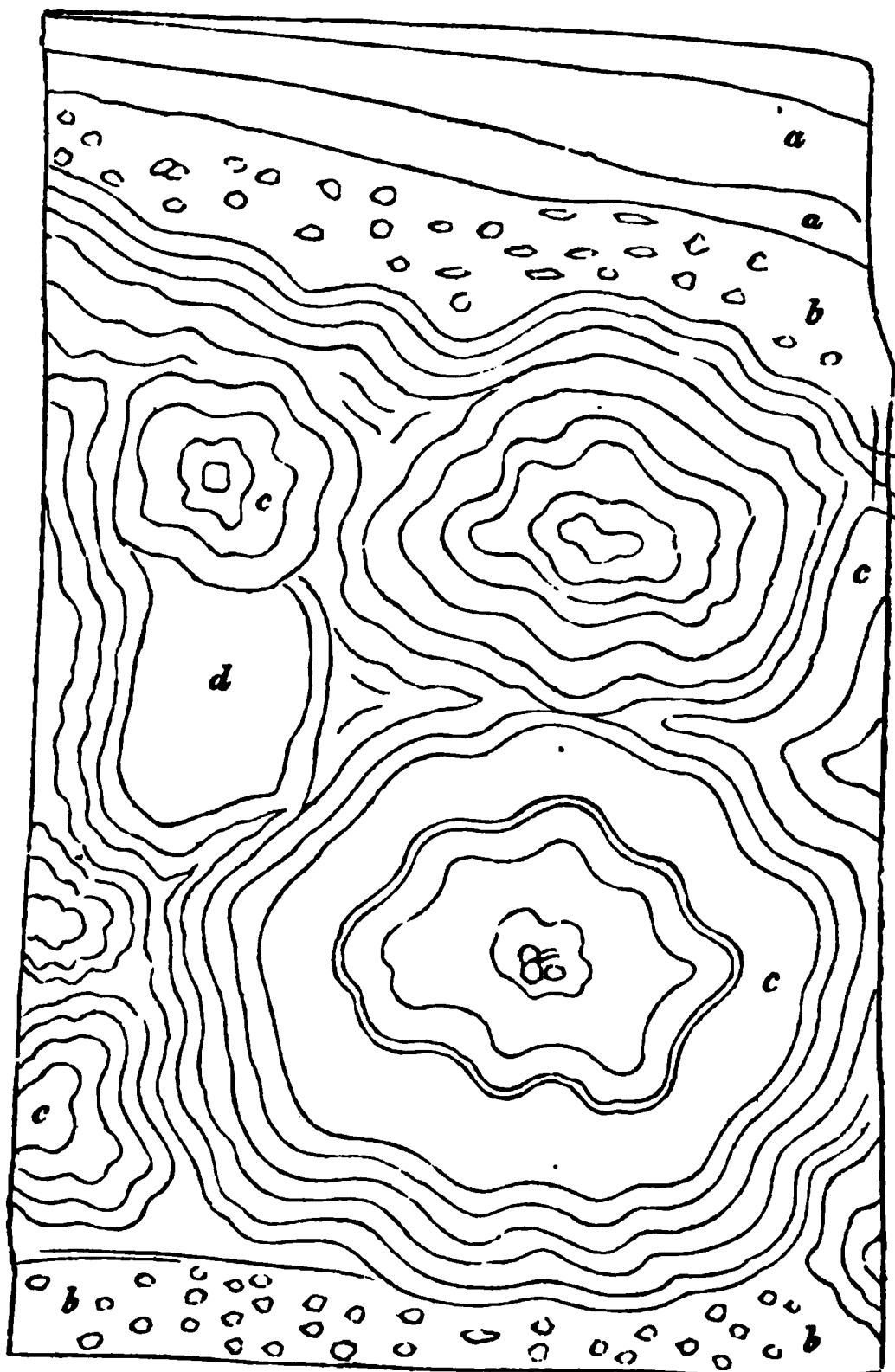
* Consolations in Travel, p. 123—125.

† Id. p. 127.

incrust the reeds which grow on its banks, and the foam of the cataract of Tivoli forms beautiful pendant stalactites; but, on the sides of the deep chasm into which the cascade throws itself, there is seen an extraordinary accumulation of horizontal beds of tufa and travertin, from four to five hundred feet in thickness. The section immediately under the temples of Vesta and the Sibyl, displays, in a precipice about four hundred feet high, some spheroids which are from *six to eight feet in diameter*, each concentric layer being about the eighth of an inch in thickness. The annexed diagram exhibits about fourteen feet of this immense mass, as seen in the path cut out of the rock in descending from the temple of Vesta to the Grotto di Nettuno. I have not attempted to express in this drawing the innumerable thin layers of which these magnificent spheroids are composed, but the lines given mark some of the natural divisions into which they are separated by minute variations in the size or colour of the laminæ. The undulations also are much smaller, in proportion to the whole circumference, than in the drawing. The beds *a a* are of hard travertin and soft tufa; below them is a pisolite (*b*), the globules being of different sizes: underneath this appears a mass of concretionary travertin (*c c*), some of the spheroids being of the above-mentioned extraordinary size. In some places (as at *d*) there is a mass of amorphous limestone, or tufa, surrounded by concentric layers. At the bottom is another bed of pisolite (*b*), in which the small nodules are about the size and shape of beans, and some of them of filberts, intermixed with some smaller oolitic grains. In the tufaceous strata, wood is seen converted into a light tufa.

The following seems the most probable explanation

No. 6.

*Section of Spheroidal Concretionary Travertin under the Cascade of Tivoli.*

of the origin of the rock in this singular position. The Anio flows through a deep irregular fissure or gorge in the Apennine limestone, which may have been caused by earthquakes. In this deep narrow channel there existed many small lakes, three of which

have been destroyed since the time of history, by the erosive action of the torrent, the last of them having remained down to the sixth century of our era.

We may suppose a similar lake of great depth to have existed at some remote period at Tivoli, and that, into this, the waters, charged with carbonate of lime, fell from a height inferior to that of the present cascade. Having, in their passage through the upper lakes, parted with their sand, pebbles, and coarse sediment, they only introduced into this lower pool drift-wood, leaves, and other buoyant substances. In seasons when the water was low, a deposit of ordinary tufa, or travertin, formed along the bottom; but at other times, when the torrent was swollen, the pool must have been greatly agitated, and every small particle of carbonate of lime which was precipitated must have been whirled round again and again in various eddies, until it acquired many concentric coats, so as to resemble oolitic grains. If the violence of the motion be sufficient to cause the globule to be suspended for a sufficient length of time, it would grow to the size of a pea, or much larger. Small fragments of vegetable stems being incrusting on the sides of the stream, and then washed in, would form the nucleus of oval globules, and others of irregular shapes would be produced by the resting of fragments for a time on the bottom of the basin, where, after acquiring an unequal thickness of travertin on one side, they would again be set in motion. Sometimes globules, projecting above the general level of a stratum, would attract, by chemical affinity, other matter in the act of precipitation, and thus growing on all sides, with the exception of the point of contact, might at length form spheroids nearly perfect and many feet in diameter. Masses

might increase above and below, so that a vertical section might afterwards present the phenomenon so common at Tivoli, where the nucleus of some of the concentric circles has the appearance of having been suspended, without support, in the water, until it became a spheroidal mass of great dimensions.

It is probable that the date of the greater portion of this calcareous formation may be anterior to the era of history, for we know that there was a great cascade at Tivoli in very ancient times; but, in the upper part of the travertin, is shown the hollow left by a wheel, in which the outer circle and the spokes have been decomposed, and the spaces which they filled have been left void. It seems impossible to explain the position of this mould, without supposing that the wheel was imbedded before the lake was drained.

Calcareous springs in the Caucasus.—Pallas, in his journey along the Caucasus, a country now subject, from time to time, to be rent and fissured by violent earthquakes, enumerates a great many hot springs, which have deposited monticules of travertin precisely analogous in composition and structure to those of the baths of San Filippo and other localities in Italy. When speaking of the tophus-stone, as he terms these limestones, he often observes that it is *snow-white*, a description which is very applicable to the newer part of the deposit at San Filippo, where it has not become darkened by weathering. In many localities in the regions between the Caspian and Black Seas, where subterranean convulsions are frequent, travellers mention calc-sinter as an abundant product of hot springs. Near the shores of the Lake Urmia (or Maragha), for example, a marble which is much used in orna-

mental architecture is rapidly deposited by a thermal spring.*

It is probable that the zoophytic and shelly limestones, which constitute the coral reefs of the Indian and Pacific Oceans, are supplied with carbonate of lime and other mineral ingredients by submarine springs, and that their heat, as well as their earthy and gaseous contents, may promote the development of corals, sponges, and testacea, just as vegetation is quickened by similar causes in the lake of the Solfatara before described. But of these reefs and their probable origin I shall again have occasion to speak in the third book.

Sulphureous and gypseous springs. — All other mineral ingredients wherewith springs in general are impregnated, are insignificant in quantity in comparison to lime, and this earth is most frequently combined with carbonic acid. But, as sulphuric acid and sulphuretted hydrogen are very frequently supplied by springs, gypsum may, perhaps, be deposited largely in certain seas and lakes. The gypseous precipitates, however, hitherto known on the land, appear to be confined to a very few springs. Those at Baden, near Vienna, which feed the public bath, may be cited as examples. Some of these supply, singly, from 600 to 1000 cubic feet of water per hour, and deposit a fine powder, composed of a mixture of sulphate of lime, with sulphur and muriate of lime.†

Siliceous springs. — *Azores.* — In order that water should hold a very large quantity of silica in solution,

* Hoff, Geschichte, &c. vol. ii. p. 114.

† C. Prevost, Essai sur la Constitution Physique du Bassin de Vienne, p. 10.

it seems necessary that it should be raised to a high temperature * ; and as it may retain a greater heat under the pressure of the sea than in the atmosphere, submarine springs may, perhaps, be more charged with silex than any to which we have access. The hot springs of the Valle das Furnas, in the Island of St. Michael, rising through volcanic rocks, precipitate vast quantities of siliceous sinter, as it is usually termed. Around the circular basin of the largest spring, called " the Caldeira," which is between twenty and thirty feet in diameter, alternate layers are seen of a coarser variety of sinter mixed with clay, including grass, ferns, and reeds, in different states of petrification. Wherever the water has flowed, sinter is found rising in some places eight or ten inches above the ordinary level of the stream. The herbage and leaves, more or less incrustated with silex, are said to exhibit all the successive steps of petrification, from the soft state to a complete conversion into stone ; but in some instances, alumina, which is likewise deposited from the hot waters, is the mineralizing material. Branches of the same ferns which now flourish in the island, are found completely petrified, preserving the same appearance as when vegetating, except that they acquire an ash-gray colour. Fragments of wood, and one entire bed from three to five feet in depth, composed of reeds now common in the island, have become completely mineralized.

The most abundant variety of siliceous sinter occurs in layers from a quarter to half an inch in thickness, accumulated on each other often to the height of a foot and upwards, and constituting parallel, and for

* Daubeny on Volcanos, p. 222.

the most part horizontal, strata many yards in extent. This sinter has often a beautiful semi-opalescent lustre. One of the varieties differs from that of Iceland and Ischia in the larger proportion of water it contains, and in the absence of alumina and lime. A recent breccia is also in the act of forming, composed of obsidian, pumice, and scorixæ, cemented by siliceous sinter.*

Geysers of Iceland. — But the hot springs in various parts of Iceland, particularly the celebrated geysers, afford the most remarkable example of the deposition of silex.† The circular reservoirs into which the geysers fall, are filled in the middle with a variety of opal, and round the edges with sinter. The plants incrustated with the latter substance have much the same appearance as those incrustated with calcareous tufa in our own country. The solution of the silex is supposed to be promoted by the presence of some mineral alkali. In some of the thermal waters of Iceland a vesicular rock is formed, containing portions of vegetables, more or less completely silicified. Amongst the various products also of springs in this island, is that admixture of clay and silica, called tripoli.

Ischia. — It has been found, by recent analysis, that several of the thermal waters of Ischia are impregnated with a certain proportion of silica. Some of the hot vapours of that island are above the temperature of boiling water: and many fissures, near Monte Vico, through which the hot steam passes, are coated with

* Dr. Webster, on the Hot Springs of Furnas, Ed. Phil. Journ., vol. vi. p. 306.

† See a cut of the Icelandic geyser, Book II. part 2. chap. 9.

a siliceous incrustation, first noticed by Dr. Thompson under the name of fiorite.

Ava, &c.—It has been often stated that the Danube has converted the external part of the piles of Trajan's bridge into silex; the Irawadi, in Ava, has been supposed, ever since the time of the Jesuit Padre Duchatz, to have the same petrifying power, as also Lough Neagh, in Ireland. Modern researches, however, in the Burman empire, have thrown doubt upon the lapidifying property of the Ava river*; there is certainly no foundation for the story in regard to Lough Neagh, and probably none in regard to the Danube.

Mineral waters, even when charged with a small proportion of silica, as those of Ischia, may supply certain species of corals and sponges with matter for their siliceous secretions; but when in a volcanic archipelago, or a region of submarine volcanos, there are springs so saturated with silica as those of Iceland or the Azores, we may expect layers and nodules of silex and chert to be spread out far and wide over the bed of the sea, and interstratified with shelly and calcareous deposits, which may be forming there, or with matter derived from wasting cliffs or volcanic ejections.

Ferruginous springs.—The waters of almost all springs contain some iron in solution; and it is a fact familiar to all, that many of them are so copiously impregnated with this metal, as to stain the rocks or herbage through which they pass, and to bind together sand and gravel into solid masses. We may naturally, then, conclude that this iron, which is constantly con-

* Dr. Buckland, Geol. Trans., second series, vol. ii. part iii. p. 384.

veyed from the interior of the earth into lakes and seas, and which does not escape again from them into the atmosphere by evaporation, must act as a colouring and cementing principle in the subaqueous deposits now in progress. It will be afterwards seen that many sandstones and other rocks in the sedimentary strata of ancient lakes and seas are bound together or coloured by iron, and this fact presents us with a striking point of analogy between the state of things at very different epochs. In those older formations we meet with great abundance of carbonate and sulphate of iron; and in chalybeate waters at present, this metal is most frequently in the state of a carbonate, as in those of Tunbridge, for example. Sulphuric acid, however, is often the solvent, which is in many cases derived from the decomposition of pyrites.

Brine springs.—Cheshire.—So great is the quantity of muriate of soda in some springs, that they yield one fourth of their weight in salt. They are rarely, however, so saturated, and generally contain, intermixed with salt, carbonate and sulphate of lime, magnesia, and other mineral ingredients. The brine springs of Cheshire are the richest in our country; those of Barton and Northwich being almost fully saturated. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock salt. The origin of the brine, therefore, may be derived in this and many other instances from beds of fossil salt; but as muriate of soda is one of the products of volcanic emanations and of springs in volcanic regions, the original source of salt may be as deep seated as that of lava.

Dead Sea.—The waters of the Dead Sea contain

scarcely any thing except muriatic salts, which lends countenance, observes Dr. Daubeny, to the volcanic origin of the surrounding country, these salts being frequent products of volcanic eruptions. Many springs in Sicily contain muriate of soda, and the "fume salso," in particular, is impregnated with so large a quantity, that cattle refuse to drink of it.

Auvergne. — A hot spring, rising through granite, at Saint Nectaire, in Auvergne, may be mentioned as one of many, containing a large proportion of muriate of soda, together with magnesia and other ingredients.*

Carbonated springs. — *Auvergne.* — Carbonic acid gas is very plentifully disengaged from springs in almost all countries, but particularly near active or extinct volcanos. This elastic fluid has the property of decomposing many of the hardest rocks with which it comes in contact, particularly that numerous class in whose composition felspar is an ingredient. It renders the oxide of iron soluble in water, and contributes, as was before stated, to the solution of calcareous matter. In volcanic districts these gaseous emanations are not confined to springs, but rise up in the state of pure gas from the soil in various places. The Grotto del Cane, near Naples, affords an example, and prodigious quantities are now annually disengaged from every part of the Limagne d'Auvergne, where it appears to have been developed in equal quantity from time immemorial. As the acid is invisible, it is not observed, except an excavation be made, wherein it immediately accumulates, so that it will extinguish a candle. There are some springs in this district, where the water is seen bubbling and boiling up with much noise, in consequence of the abundant disengage-

* Annales de l'Auvergne, tome i. p. 234.

ment of this gas. The whole vegetation is affected, and many trees, such as the walnut, flourish more luxuriantly than they would otherwise do in the same soil and climate,—the leaves probably absorbing carbonic acid. This gas is found in springs rising through the granite near Clermont, as well as in the tertiary limestones of the Limagne.* In the environs of Pont-Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead-mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked.† Not far off is the small volcanic cone of Chaluzet, which once broke up through the gneiss, and sent forth a lava-stream.

Disintegration of granite.—The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Clermont. This decay was called by Dolomieu, “la maladie du granite;” and the rock may with propriety be said to have *the rot*, for it crumbles to pieces in the hand. The phenomenon may, without doubt, be ascribed to the continual disengagement of carbonic acid gas from numerous fissures.

In the plains of the Po, between Verona and Parma, especially at Villa Franca, south of Mantua, I observed great beds of alluvium, consisting chiefly of primary pebbles percolated by spring water, charged with carbonate of lime and carbonic acid in great abundance. They are for the most part incrustated with

* Le Coq, Annales de l'Auvergne, tome i. p. 217. May, 1828.

† Ann. Scient. de l'Auvergne, tome ii. June, 1829.

calc-sinter: and the rounded blocks of gneiss, which have all the outward appearance of solidity, have been so disintegrated by the carbonic acid as readily to fall to pieces.

The subtraction of many of the elements of rocks by the solvent power of carbonic acid, ascending both in a gaseous state and mixed with spring-water in the crevices of rocks, must be one of the most powerful sources of those internal changes and re-arrangements of particles so often observed in strata of every age. The calcareous matter, for example, of shells is often entirely removed and replaced by carbonate of iron, pyrites, silex, or some other ingredient, such as mineral waters usually contain in solution. It rarely happens, except in limestone rocks, that the carbonic acid can dissolve all the constituent parts of the mass; and for this reason, probably, calcareous rocks are almost the only ones in which great caverns and long winding passages are found.

Petroleum springs. — Springs impregnated with petroleum, and the various minerals allied to it, as bitumen, naphtha, asphaltum, and pitch, are very numerous, and are, in many cases, undoubtedly connected with subterranean fires, which raise or sublime the more subtle parts of the bituminous matters contained in rocks. Many springs in the territory of Modena and Parma, in Sicily, produce petroleum in abundance; but the most powerful, perhaps, yet known, are those on the Irawadi, in the Burman empire. In one locality there are said to be 520 wells, which yield annually 400,000 hogsheads of petroleum.*

* Symes, Embassy to Ava, vol. ii. — Geol. Trans., second series, vol. ii. part iii. p. 388.

Fluid bitumen is seen to ooze from the bottom of the sea, on both sides of the island of Trinidad, and to rise up to the surface of the water. Near Cape La Braye there is a vortex which, in stormy weather, according to Captain Mallet, gushes out, raising the water five or six feet, and covers the surface for a considerable space with petroleum, or tar; and the same author quotes Gumilla, as stating in his "Description of the Orinoco," that, about seventy years ago, a spot of land on the western coast of Trinidad, near half-way between the capital and an Indian village, sank suddenly, and was immediately replaced by a small lake of pitch, to the great terror of the inhabitants.*

Pitch lake of Trinidad.—It is probable that the great pitch lake of Trinidad owes its origin to a similar cause; and Dr. Nugent has justly remarked, that in that district all the circumstances are now combined from which deposits of pitch may have originated. The Orinoco has for ages been rolling down great quantities of woody and vegetable bodies into the surrounding sea, where, by the influence of currents and eddies, they may be arrested and accumulated in particular places. The frequent occurrence of earthquakes and other indications of volcanic action in those parts lend countenance to the opinion, that these vegetable substances may have undergone, by the agency of subterranean fire, those transformations and chemical changes which produce petroleum, and this may, by the same causes, be forced up to the surface, where, by exposure to the air, it becomes inspissated, and forms the different varieties of pure and earthy pitch, or asphaltum, so abundant in the island.†

* Dr. Nugent, Geol. Trans. vol. i. p. 69. † Ibid. p. 67.

The bituminous shales, so common in geological formations of different ages, as also many stratified deposits of bitumen and pitch, seem clearly to attest that, at former periods, springs, in various parts of the world, were as commonly impregnated as now with bituminous matter, carried down, probably, by rivers into lakes and seas. It will, indeed, be easy to show, that a large portion of the finer particles and the more crystalline substances found in sedimentary rocks of different ages are composed of the same elements as are now held in solution by springs, while the coarser materials bear an equally strong resemblance to the alluvial matter in the beds of existing torrents and rivers.

CHAPTER IV.

REPRODUCTIVE EFFECTS OF RUNNING WATER.

Reproductive effects of running water — Division of Deltas into lacustrine, mediterranean, and oceanic — Lake deltas — Growth of the delta of the Rhone in the Lake of Geneva — Chronological computations of the age of deltas — Recent deposits in Lake Superior — Deltas of inland seas — Rapid shallowing of the Baltic — Supposed gradual elevation of the coast of Scandinavia — Elevated beaches on the coast of Sweden — Marine delta of the Rhone — Various proofs of its increase — Stony nature of its deposits — Delta of the Po, Adige, Isonzo, and other rivers entering the Adriatic — Rapid conversion of that gulf into land — Mineral characters of the new deposits — Delta of the Nile — Its increase since the time of Homer — Its growth why checked at present.

HAVING considered the destroying and transporting agency of running water, we have now to examine the reproductive effects of the same cause. The aggregate amount of deposits accumulated in a given time at the mouths of rivers, where they enter a lake or sea, affords clearer data for estimating the energy of the excavating power of running water on the land, than the separate study of the operations of the same cause in the countless ramifications into which every great system of valleys is divided. I shall therefore proceed to select some of the leading facts at present ascertained respecting the growth of deltas, and shall then offer some general observations on the quantity of sediment transported by rivers, and the manner of its distribution beneath the waters of lakes and seas.

Division of deltas into lacustrine, mediterranean, and oceanic.—Deltas may be divided into, first, those which are formed in lakes; secondly, those in inland seas; and thirdly, those on the borders of the ocean. The most characteristic distinction between the lacustrine and marine deltas consists in the nature of the organic remains, which become imbedded in their deposits, for, in the case of a lake, it is obvious that these must consist exclusively of such genera of animals as inhabit the land or the waters of a river or lake; whereas, in the other case, there will be an admixture and most frequently a predominance of animals which inhabit salt water. In regard, however, to the distribution of inorganic matter, the deposits of lakes and inland seas are formed under very analogous circumstances, and may be distinguished from those on the shores of the great ocean, where the tides co-operating with currents give rise to another class of phenomena. In lakes and inland seas, even of the largest dimensions, the tides are almost insensible, but the currents, as will afterwards appear, sometimes run with considerable velocity.

DELTA IN LAKES.

Lake of Geneva.—It is natural to begin our examination with an inquiry into the new deposits in lakes, as they exemplify the first reproductive operations in which rivers are engaged when they convey the detritus of rocks and the ingredients of mineral springs from mountainous regions. The accession of new land at the mouth of the Rhone, at the upper end of the Lake of Geneva, or the Lemman Lake, presents us with

an example of a considerable thickness of strata which have accumulated since the historical era. This sheet of water is about thirty-seven miles long, and its breadth is from two to eight miles. The shape of the bottom is very irregular, the depth having been found, by late measurements, to vary from 20 to 160 fathoms.* The Rhoné, where it enters at the upper end, is turbid and discoloured; but its waters, where it issues at the town of Geneva, are beautifully clear and transparent. An ancient town, called Port Vallais, (*Portus Valesiæ* of the Romans,) once situated at the water's edge, at the upper end, is now more than a mile and a half inland,—this intervening alluvial tract having been acquired in about eight centuries. The remainder of the delta consists of a flat alluvial plain, about five or six miles in length, composed of sand and mud, a little raised above the level of the river, and full of marshes.

Mr. De la Beche found, after numerous soundings in all parts of the lake, that there was a pretty uniform depth of from 120 to 160 fathoms throughout the central region, and, on approaching the delta, the shallowing of the bottom began to be very sensible at a distance of about a mile and three-quarters from the mouth of the Rhone; for a line drawn from St. Gingoulph to Vevey, gives a mean depth of somewhat less than six hundred feet, and from that part to the Rhone, the fluviatile mud is always found along the bottom.† We may state, therefore, that the strata annually produced are about two miles in length: so that, notwithstanding the great depth of the lake, the new deposits are not inclined at a high angle; the dip of the beds,

* De la Beche, Ed. Phil. Journ. vol. ii. p. 107. Jan. 1820.

† De la Beche, MS.

indeed, is so slight, that they would be termed, in ordinary geological language, horizontal.

The strata probably consist of alternations of finer and coarser particles, for, during the hotter months from April to August, when the snows melt, the volume and velocity of the river are greatest, and large quantities of sand, mud, vegetable matter, and drift-wood are introduced; but, during the rest of the year, the influx is comparatively feeble, so much so, that the whole lake, according to Saussure, stands six feet lower. If, then, we could obtain a section of the accumulation formed in the last eight centuries, we should see a great series of strata, probably from 600 to 900 feet thick, and nearly two miles in length, inclined at a very slight angle. In the mean time, a great number of smaller deltas are growing around the borders of the lake, at the mouths of rapid torrents, which pour in large masses of sand and pebbles. The body of water in these torrents is too small to enable them to spread out the transported matter over so extensive an area as the Rhone. Thus, for example, there is a depth of eighty fathoms within half a mile of the shore, immediately opposite the great torrent which enters east of Ripaille, so that the dip of the strata in that minor delta must be about four times as great as those deposited by the main river at the upper extremity of the lake.*

Chronological computations of the age of deltas.—The capacity of this basin being now ascertained, it would be an interesting subject of inquiry, to determine in what number of years the Lemman Lake will be converted into dry land. It would not be very difficult to

* De la Beche, MS.

obtain the elements for such a calculation, so as to approximate at least to the quantity of time required for the accomplishment of the result. The number of cubic feet of water annually discharged by the river into the lake being estimated, experiments might be made in the winter and summer months, to determine the proportion of matter held in suspension or in chemical solution by the Rhone. It would be also necessary to allow for the heavier matter drifted along at the bottom, which might be estimated on hydrostatical principles, when the average size of the gravel and the volume and velocity of the stream at different seasons were known. Supposing all these observations to have been made, it would be more easy to calculate the future than the former progress of the delta, because it would be a laborious task to ascertain, with any degree of precision, the original depth and extent of that part of the lake which is already filled up. Even if this information were actually obtained by borings, it would only enable us to approximate within a certain number of centuries to the time when the Rhone began to form its present delta; but this would not give us the date of the origin of the Lemman Lake in its present form, because the river may have flowed into it for thousands of years, without importing any sediment whatever. Such would have been the case, if the waters had first passed through a chain of upper lakes; and that this was actually the fact, is indicated by the course of the Rhone between Martigny and the Lake of Geneva, and still more decidedly, by the channels of many of its principal feeders.

If we ascend, for example, the valley through which the Dranse flows, we find that it consists of a succession

of basins, one above the other, in each of which there is a wide expanse of flat alluvial lands, separated from the next basin by a rocky gorge, once evidently the barrier of a lake. The river has filled these lakes, one after the other, and has partially cut through the barriers, which it is still gradually eroding to a greater depth. The examination of almost all valleys in mountainous districts affords similar proofs of the obliteration of a series of lakes, by the filling up of hollows and the cutting through of rocky barriers—a process by which running water ever labours to produce a more uniform declivity. Before, therefore, we can pretend even to hazard a conjecture as to the era at which any particular delta commenced, we must be thoroughly acquainted with the geographical features and geological history of the whole system of higher valleys which communicate with the main stream, and all the changes which they have undergone since the last series of convulsions which agitated and altered the face of the country.

The probability, therefore, of error in our chronological computations, where we omit to pay due attention to these circumstances, increases in proportion to the time that may have elapsed since the last disturbance of the country by subterranean movements, and in proportion to the extent of the hydrographical basin on which we may happen to speculate. The Alpine rivers of Vallais are prevented at present from contributing their sedimentary contingent to the lower delta of the Rhone in the Mediterranean, because they are intercepted by the Lemman Lake; but when this is filled, they will transport as much, or nearly as much, matter to the sea as they now pour into that lake. They will then flow through a long, flat, alluvial plain, between

Villeneuve and Geneva, from two to eight miles in breadth, which will present no superficial marks of the existence of a thickness of more than one thousand feet of recent sediment below. Many hundred alluvial tracts of equal, and some of much greater area, may be seen if we follow up the Rhone from its termination in the Mediterranean, or explore the valleys of many of its principal tributaries.

What, then, shall we think of the presumption of De Luc, Kirwan, and their followers, who confidently deduced from the phenomena of modern deltas the recent origin of the present form of our continents, without pretending to have collected any one of the numerous data by which so complicated a problem can be solved? Had they, after making all the necessary investigations, succeeded in proving, as they desired, that the lower delta of the Rhone, and the new deposits at the mouths of several other rivers, whether in lakes or seas, had required about four thousand years to attain their present dimensions, the conclusion would have been fatal to the chronological theories which they were anxious to confirm.

Lake Superior.—Lake Superior is the largest body of fresh water in the world, being about 1500 geographical miles in circumference, when we follow the sinuosities of its coasts, and its length, on a curved line drawn through its centre, being about 360, and its extreme breadth 140 geographical miles. Its average depth varies from 80 to 150 fathoms; but, according to Captain Bayfield, there is reason to think that its greatest depth would not be overrated at two hundred fathoms*, so that its bottom is, in some parts,

* Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

nearly six hundred feet below the level of the Atlantic, its surface about as much above it. There are appearances in different parts of this, as of the other Canadian lakes, leading us to infer that its waters formerly occupied a much higher level than they reach at present; for at a considerable distance from the present shores, parallel lines of rolled stones and shells are seen rising one above the other, like the seats of an amphitheatre. These ancient lines of shingle are exactly similar to the present beaches in most bays, and they often attain an elevation of forty or fifty feet above the present level.

As the heaviest gales of wind do not raise the waters more than three or four feet*, the elevated beaches must either be referred to the subsidence of the lake at former periods, in consequence of the wearing down of its barrier, or to the upraising of the shores by earthquakes, like those which have produced similar phenomena on the coast of Chili. The streams which discharge their waters into Lake Superior are several hundred in number, without reckoning those of smaller size; and the quantity of water supplied by them is many times greater than that discharged at the Falls of St. Mary, the only outlet. The evaporation, therefore, is very great, and such as might be expected from so vast an extent of surface.

On the northern side, which is encircled by primary mountains, the rivers sweep in many large boulders

* Captain Bayfield remarks, that Dr. Bigsby, to whom we are indebted for several communications respecting the geology of the Canadian lakes, was misinformed by the fur traders in regard to the extraordinary height (twenty or thirty feet) to which he asserts that the autumnal gales will raise the water of Lake Superior. — Ibid. p. 7.

with smaller gravel and sand, chiefly composed of granitic and trap rocks. There are also currents in the lake, in various directions, caused by the continued prevalence of strong winds, and to their influence we may attribute the diffusion of finer mud far and wide over great areas; for, by numerous soundings made during the late survey, it was ascertained that the bottom consists generally of a very adhesive clay, containing shells of the species at present existing in the lake. When exposed to the air, this clay immediately becomes indurated in so great a degree, as to require a smart blow to break it. It effervesces slightly with diluted nitric acid, and is of different colours in different parts of the lake; in one district blue, in another red, and in a third white, hardening into a substance resembling pipe-clay.* From these statements, the geologist will not fail to remark how closely these recent lacustrine formations in America resemble the tertiary argillaceous and calcareous marls of lacustrine origin in Central France. In both cases, many of the genera of shells most abundant, as *Lymnea* and *Planorbis*, are the same; and in regard to other classes of organic remains, there must be the closest analogy, as I shall endeavour more fully to explain when speaking of the imbedding of plants and animals in recent deposits.

DELTAS OF INLAND SEAS.

Supposed diminution of level in the Baltic.—Having thus briefly considered some of the lacustrine deltas

* Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

now in progress, we may next turn our attention to those of inland seas.

The shallowing and conversion into land of many parts of the Baltic, especially the Gulfs of Bothnia and Finland, have been demonstrated by a series of accurate observations, for which we are in a great measure indebted to the animated controversy which has been kept up, since the middle of the last century, concerning the gradual lowering of the level of the Baltic. Celsius, the Swedish naturalist, first originated the idea, that from the earliest times there had been a progressive fall of about forty-five inches in a century, in the mean level of the waters of that sea. He contended that this change rested not only on modern observations, but on the authority of the ancient geographers, who stated that Scandinavia was formerly an island. By the gradual depression of the sea, that great island, he said, became connected with the continent; and this event happened after the time of Pliny, and before the ninth century of our era.

To the arguments urged in support of these positions, his opponents objected that the ancients were so ignorant of the geography of the most northern parts of Europe, that their authority was entitled to no weight; and that their representation of Scandinavia as an island, might with more propriety be adduced to prove the scantiness of their information, than to confirm so bold an hypothesis. It was also remarked, that if the land which connected Scandinavia with the main continent was laid dry between the time of Pliny and the ninth century, to the extent to which it is known to have risen above the sea at the latter period, the rate of depression could not have been uniform, as was pretended, for it ought to have fallen

much more rapidly between the ninth and eighteenth centuries.

Many of the physical proofs relied on by Celsius and his followers show clearly that they did not sufficiently distinguish between the shallowing of the water by deposition of fresh sediment, and that which might arise from a subsidence of the sea. By their own statements, it appeared that the accessions of new land, and the loss of depth, were at the mouths of rivers, or in certain deep bays, into which it is well known that sand and mud are carried by currents. As illustrating, however, the gradual conversion of the Gulf of Bothnia into land, their observations deserve great attention. Thus, for example, they pointed out the fact, that at Pitea half a mile was gained in forty-five years, and at Lulea no less than a mile in twenty-eight years. Ancient ports on the same coast had become inland cities. Considerable tracts of the gulf were rendered three feet shallower in the course of fifty years — many old fishing-grounds had been changed into dry land — small islands had been joined to the continent. According to Linnæus, the annual increase of land on the eastern side of Gothland, near Hoburg, had been for ninety years at the rate of from twelve to eighteen feet in extent.*

Besides these changes, it was asserted that, along the southern shore of the Baltic, particularly in West Prussia and Pomerania, anchors and sunk ships had been discovered far inland; and although these occurrences were partly accounted for by the mere silting up of river-beds, yet the tradition seems worthy of credit, that a bay of the sea penetrated,

* Linn. de tell. habit. increm.

at a remote period, much farther to the south in that direction.

Other arguments of Celsius were derived from the alleged exposure of certain insular rocks in the Bothnian and other bays, which were declared to have been once entirely covered with water, but which had gradually protruded themselves more and more above the waves, until, in the course of about a century and a half, they grew to be eight feet high. Of this phenomenon the following explanation was offered by his opponents. The islands in question consisted of sand and drift-stones, and the waves, during great tempests, threw up new matter upon them, or converted shoals into islands. Sometimes, also, icebergs, heavily laden with rock, were stranded on a shoal or driven up on a low island; and when they melted away, they left a mass of débris, many feet in height.

Browallius, and other Swedish naturalists, pointed out that some of these islands were lower than formerly; so that, by reference to this kind of evidence, there was equally good reason for contending that the level of the Baltic was gradually rising. They also added another curious and very conclusive proof of the permanency of the water-level for many centuries. On the Finland coast were some large pines, growing close to the water's edge; these were cut down, and, by counting the concentric rings of annual growth, as seen in a transverse section of the trunk, it was demonstrated that they had stood there for four hundred years. Now, according to the Celsiusian hypothesis, the sea had sunk about fifteen feet during that period, in which case the germination and early growth of these pines must have been for many

seasons below the level of the water. In like manner it was shown, that the lower walls of many ancient castles, such as those of Sonderburg and Abo, reached then to the water's edge, and must, therefore, according to the theory of Celsius, have been originally constructed below the level of the sea.

Another unanswerable argument in proof of the stability of the level of the Baltic was drawn from the island of Saltholm, not far from Copenhagen. This isle is so low that, in autumn and winter, it is permanently overflowed; and it is only dry in summer, when it serves for pasturing cattle. It appears, from documents of the year 1280, that this island was then also in the same state, and exactly on a level with the mean height of the sea, instead of having been twenty feet under water, as it ought to have been according to the computation of Celsius. Several towns, also, on the shores of the Baltic, as Lubeck, Wismar, Rostock, Stralsund, and others, after six and even eight hundred years, are as little elevated above the sea as at the era of their foundation, being now close to the water's edge. The lowest part of Dantzic was no higher than the mean level of the sea in the year 1000; and after eight centuries its relative position remains exactly the same.*

These facts sufficiently demonstrate that the waters of the Baltic are not retiring every where; accordingly, Haussman and Von Buch, both of whom are intimately acquainted with the Scandinavian peninsula, have advanced the opinion, that the land itself bordering a considerable part of the Baltic is slowly and insensibly

* For a full account of the Celsian controversy, we may refer our readers to Von Hoff, *Geschichte*, &c. vol. i. p. 439.

rising. The attention excited by this subject in the early part of the last century induced many of the Swedish philosophers to determine, by a series of observations, the mean height of the waters of the Baltic; and under their direction, lines representing the true elevation were chiselled out upon the rocks, at different favourable positions along the coast. Similar observations have since been repeated at various intervals, the most recent and extensive having been made in 1821, under the joint direction of the Swedish Academy and the Russian Minister of Marine. The result, we are assured, of all these comparative admeasurements is, that along the greater part of the Baltic the mean level of the water is falling from three to five feet in a century, or about one foot in every twenty-five years.

Mr. Johnston, in a recent paper on this subject*, states, that, after a careful inspection of the country, particularly the shores of Lake Maeler and other inland waters around Stockholm, he has convinced himself that a change in the relative position of land and sea is in progress. Several of the small peninsulas, he says, on which the city and suburbs stand, were formerly islands; and during the summer of 1832, two canals were in progress across narrow necks of land, for the purpose of reviving a communication, said to have been interrupted by the gradual elevation of the

* On the Elevation of Land in Scandinavia, Ed. New Phil. Journ. No. 29. p. 34. The facts stated in this memoir have induced me somewhat to modify the opinion expressed in former editions, respecting the rise of part of Scandinavia. I am willing to hope that a personal examination of the country will soon entirely remove from my mind all remaining scepticism.

country. A small part of the lower city of Stockholm is built upon piles, and the security, therefore, of the buildings depends upon the piles being constantly under water. But after a lapse of years, some of them were observed to be giving way, and on searching for the cause, it was found that the sinking of the water had gradually left bare their tops, and exposed them to decay. The same author remarks, that the southernmost part of the coast of Sweden, and probably a part of Finland, and the whole southern shores of the Baltic, do not participate in this elevatory movement, which, nevertheless, prevails through a tract of country, stretching from the head of the Bothnian Gulf to Norkoping, south of Stockholm; a tract about equal in length from N. to S. to the whole of England proper.

Mr. Everest, in his late work (Travels through Norway), informs us that the small island of Munkholm, on the shores of Norway, affords conclusive evidence of the land having in that region remained stationary for the last eight centuries. The area of this isle does not exceed that of a small village, and by an official survey, its highest point has been determined to be twenty-three feet above the mean high water mark, that is, the mean between neap and spring tides. Now, a monastery was founded there by Canute the Great, A.D. 1028, and thirty-three years before that time it was in use as a common place of execution. According to the assumed average rate of rise in Sweden (about forty inches in a century), we should be obliged to suppose that this island had been three feet eight inches below high water mark when it was originally chosen as the site of the monastery.

Now one ground of reluctance which we naturally

entertain towards the proposed theory of elevation is this, that so many of the phenomena first quoted in support of it are such as may be observed generally at the mouths of rivers, on coasts where we know that there is no uplifting of the country in progress. At the same time it must be conceded, that if the shores and bed of the Baltic are gradually rising, the appearances which would first strike every observer would be the rapid gain of land on those spots where the sea had previously been rendered shallow by the importation of sediment by rivers and currents. At a distance from these points, where the scarped granitic rocks plunge at once into deep water, a very considerable rise of the coast would be required, to produce any conspicuous change in the relative area of sea and land.

The next objection that arises, is the absence of all traces of volcanic action in Norway and Sweden; and the fact that no countries have been more entirely free from earthquakes, since the times of authentic history. In common with our own island, and, indeed, with almost every spot on the globe, they have experienced some slight shocks at certain periods, as during the earthquake of Lisbon, and on a few other occasions, but these may rather be considered as prolonged vibrations in the shell of the earth, extending in the manner of sounds through the air to almost indefinite distances, than as those violent movements which in the great regions of active volcanos change, from time to time, the relative level of the land and sea.

Besides these objections, the variations of level in volcanic countries, so far as they have yet been observed, take place by starts, and not by a succession of small

imperceptible alterations, as is described to be the case in Scandinavia.

The next source of doubt which may reasonably suggest itself, is founded on the difficulty of determining with minute exactness the mean level of the sea, even where there are no tides, as in the Baltic. It is known that this sea is raised several feet, or lowered to the same amount, by the prevalence of easterly or westerly winds. The surveyors, it is true, in 1821, were on their guard as much as possible against this cause of deception; endeavouring to approximate to the true level of the waters, by taking the mean between the maximum and minimum of their height. But it is quite conceivable, that a damming back of the waters, by a different set of the currents, might exist at one period and not at another.

The evaporation of the Baltic is known to be insufficient to counterbalance the influx of river-water of which it is the receptacle, so that it is brackish, and so nearly fresh in some parts as to be inhabited by fluviatile testacea. Its condition is the converse of that of the Mediterranean, which is only enabled to maintain its level by borrowing largely from the Atlantic; whereas the Baltic is said, like the Black Sea, to discharge upon the whole a considerable body of surplus water. Suppose the tides, which enter by three distinct narrow channels, the Belts and the Sound, to have occasioned at some former period a greater obstruction to the free evacuation of the inland sea, so that the mean level of the Baltic was permanently higher. Let us then imagine such a widening or deepening of the channels of efflux, as to let out the waters more freely; this would produce a fall in their level, without in the slightest degree

affecting the general level of the German Ocean and Atlantic. If, however, it can be placed beyond all doubt, that in a narrow gulf, such as that of Bothnia, there has been an apparent sinking of the waters on one side at Stockholm, to the amount of several feet, and none within the same period on the opposite coast at Abo, it will then be impossible to explain the phenomena by any conjecture of this kind.

Such, then, being the present state of the evidence so far as it is derived from history and recent observation, we may next inquire whether the *geologist* can discover any signs of the upheaving of the Scandinavian coasts, within periods which he is entitled to term modern in his chronology.

Such indications have certainly presented themselves. Von Buch discovered in Norway, and at Uddevalla in Sweden, beds of shells of existing species at considerable heights above the level of the water. Since that time, several other naturalists have confirmed his observations; and, according to Ström, some deposits occur at an elevation of more than four hundred feet above the sea, in the northern part of Norway. M. Alex. Brongniart, who has lately visited Uddevalla in Gotheborg, a port at the entrance of the Baltic, informs us that the principal mass of shells in the creek of Uddevalla rises about two hundred feet above the level of the sea, resting on rocks of gneiss. All the species are identical with those now inhabiting the contiguous sea, and are for the most part entire, although some of them are broken, as happens on a sea-beach. They are nearly free from any admixture of earthy matter. On our own coasts, the rocks, where they are alternately submerged and laid dry by the ebbing and flowing tide, are frequently covered

with barnacles or balani, which are firmly attached : now, on examining with care the smooth surface of the gneiss, immediately above the ancient shelly beach at Uddevalla, M. Brongniart found, in a similar manner, balani adhering to the rocks, so that there can be no doubt that the sea had for a long period sojourned on the spot.*

These high beaches establish the important, and certainly very unexpected fact, that the Norwegian and Swedish coasts have changed their level greatly within the present geological era, or since the waters were inhabited by species now our contemporaries.

If the ancient beach at Uddevalla were brought into its present position by a process as slow and gradual as that which is now supposed to elevate the Swedish coast, the operation must have required about five thousand years for its accomplishment, and, according to the same computation, some deposits of recent shells in Norway may be of twice that antiquity ; but it would be necessary to have the recorded observations of many thousand years, before we could presume to ascribe so uniform a rate to the upheaving force.

In regard to the possible causes of a gradual upward movement of a large district, they will be more appropriately discussed, when the nature of volcanic agency shall come under review. It is enough at present to state, that there is a considerable deposition of sediment going on in the Baltic, by which it is becoming converted into land ; but that, in addition to this cause, it is the general belief not only of the people of Sweden generally, but of their philosophers, as also of several scientific foreigners who have travelled in that country, that the waters are retreating from the

* Tableau des Terrains, &c. p. 89. 1829.

land, even where not dispossessed of their place by the influx of sediment.

Delta of the Rhone.—We may now turn our attention to some of the principal deltas of the Mediterranean, for no other inland sea affords so many examples of accessions of new lands at the mouths of rivers within the records of authentic history. The lacustrine delta of the Rhone in Switzerland has already been considered, and its contemporaneous marine delta may now be described. Scarcely has the river passed out of the Lemman Lake, before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic detritus annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives vast contributions of transported matter from the Alps of Dauphiny, and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolours the blue waters of that sea with a whitish sediment, for the distance of between six and seven miles, throughout which space the current of fresh water is perceptible.

Proofs of its increase since historical periods.—Strabo's description of the delta is so inapplicable to its present configuration, as to attest a complete alteration in the physical features of the country since the Augustan age. It appears, however, that the head of the delta, or the point at which it begins to ramify, has remained unaltered since the time of Pliny, for he states that the Rhone divided itself at Arles into two arms. This is the case at present; one of the branches being now called Le petit Rhône, which is again subdivided before entering the Mediterranean. The advance of the

base of the delta, in the last eighteen centuries, is demonstrated by many curious antiquarian monuments. The most striking of these is the great detour made by the old Roman road from Ugernum to Beziers (part of the high road between Aix, Aquæ Sextiæ, and Nismes, Nemausus). It is clear that, when this was first constructed, it was impossible to pass in a direct line as now, across the delta, and that either the sea or marshes intervened in a tract now consisting of terra firma.* Astruc also remarks, that all the places on low lands, lying to the north of the old Roman road between Nismes and Beziers, have names of Celtic origin, evidently given to them by the first inhabitants of the country; whereas the places lying south of that road, towards the sea, have names of Latin derivation, and were clearly founded after the Roman language had been introduced.

Another proof, also, of the great extent of land which has come into existence since the Romans conquered and colonized Gaul, is derived from the fact, that the Roman writers never mention the thermal waters of Balaruc in the delta, although they were well acquainted with those of Aix, and others, still more distant, and attached great importance to them, as they invariably did to all hot springs. The waters of Balaruc, therefore, must have formerly issued under the sea—a common phenomenon on the borders of the Mediterranean; and on the advance of the delta they continued to flow out through the new deposits.

Among the more direct proofs of the increase of land, we find that Mese, described under the appellation of Mesua Collis by Pomponius Mela†, and stated

* Mém. d'Astruc, cited by Von Hoff, vol. i. p. 228.

† Lib. II. c. v.

by him to be nearly an island, is now far inland. Notre Dame des Ports, also, was a harbour in 898, but is now a league from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn become useless to mariners; which may well be conceived, when we state that the tower of Tignaux, erected on the shore so late as the year 1737, is already a French mile remote from it.*

By the confluence of the Rhone and the currents of the Mediterranean, driven by winds from the south, sand-bars are often formed across the mouths of the river: by these means considerable spaces become divided off from the sea, and subsequently from the river also, when it shifts its channels of efflux. As some of these lagoons are subject to the occasional ingress of the river when flooded, and of the sea during storms, they are alternately salt and fresh. Others, after being filled with salt water, are often lowered by evaporation till they become more salt than the sea; and it has happened, occasionally, that a considerable precipitate of muriate of soda has taken place in these natural salterns. During the latter part of Napoleon's career, when the excise laws were enforced with extreme rigour, the police was employed to prevent such salt from being used. The fluviatile and marine shells enclosed in these small lakes often live together in brackish water; but the uncongenial nature of the fluid usually produces a dwarfish size,

* Bouche, *Chorographie et Hist. de Provence*, vol. i. p. 23., cited by Hoff, vol. i. p. 290.

and sometimes gives rise to strange varieties in form and colour.

Captain Smyth, in the late survey of the coast of the Mediterranean, found the sea, opposite the mouth of the Rhone, to deepen gradually from four to forty fathoms, within a distance of six or seven miles, over which the discoloured fresh water extends; so that the inclination of the new deposits must be too slight to be appreciable in such an extent of section as a geologist usually obtains in examining ancient formations. When the wind blew from the south-west, the ships employed in the survey were obliged to quit their moorings; and when they returned, the new sand-banks in the delta were found covered over with a great abundance of marine shells. By this means, we learn how occasional beds of drifted marine shells may become interstratified with fresh-water strata at a river's mouth.

Stony nature of its deposits.— That a great proportion, at least, of the new deposit in the delta of the Rhone consists of *rock*, and not of loose incoherent matter, is perfectly ascertained. In the Museum at Montpellier is a cannon taken up from the sea near the mouth of the river, imbedded in a crystalline calcareous rock. Large masses, also, are continually taken up of an arenaceous rock, cemented by calcareous matter, including multitudes of broken shells of recent species. The observations recently made on this subject corroborate the former statement of Marsilli*, that the earthy deposits of the coast of Languedoc form a stony substance, for which reason he ascribed a certain bituminous, saline, and glutinous nature to

* Hist. Phys. de la Mer.

the substances brought down with sand by the Rhone. If the number of mineral springs charged with carbonate of lime which fall into the Rhone and its feeders in different parts of France be considered, we shall feel no surprise at the lapidification of the newly-deposited sediment in this delta. It should be remembered, that the fresh water introduced by rivers, being lighter than the water of the sea, floats over the latter, and remains upon the surface for a considerable distance. Consequently, it is exposed to as much evaporation as the waters of a lake ; and the area over which the river-water is spread, at the junction of great rivers and the sea, may well be compared, in point of extent, to that of considerable lakes.

Now, it is well known, that so great is the quantity of water carried off by evaporation in some lakes, that it is nearly equal to the water flowing in ; and in some inland seas, as the Caspian, it is quite equal. We may, therefore, well suppose, that, in cases where a strong current does not interfere, the greater portion not only of the matter held mechanically in suspension, but of that also which is in chemical solution, may be precipitated at no great distance from the shore. When these finer ingredients are extremely small in quantity, they may only suffice to supply crustaceous animals, corals, and marine plants, with the earthy particles necessary for their secretions ; but whenever it is in excess (as generally happens if the basin of a river lie partly in a district of active or extinct volcanos), then will solid deposits be formed, and the shells will at once be included in a rocky mass.

Delta of the Po.—The Adriatic presents a great combination of circumstances favourable to the rapid formation of deltas—a gulf receding far into the land,

— a sea without tides or strong currents, and the influx of two great rivers, the Po and the Adige, besides numerous minor streams, draining on the one side a great crescent of the Alps, and on the other some of the loftiest ridges of the Apennines. From the northernmost point of the Gulf of Trieste, where the Isonzo enters, down to the south of Ravenna, there is an uninterrupted series of recent accessions of land, more than one hundred miles in length, which, within the last two thousand years, have increased from *two to twenty miles in breadth*. The Isonzo, Tagliamento, Piave, Brenta, Adige, and Po, besides many other inferior rivers, contribute to the advance of the coast-line, and to the shallowing of the gulf. The Po and the Adige may now be considered as entering by one common delta, for two branches of the Adige are connected with arms of the Po.

In consequence of the great concentration of the flooded waters of these streams since the system of embankment became general, the rate of encroachment of the new land upon the Adriatic, especially at that point where the Po and Adige enter, is said to have been greatly accelerated. Adria was a seaport in the time of Augustus, and had, in ancient times, given its name to the gulf; it is now about twenty Italian miles inland. Ravenna was also a seaport, and is now about four Italian miles from the main sea. Yet even before the practice of embankment was introduced, the alluvium of the Po advanced with rapidity on the Adriatic; for Spina, a very ancient city, originally built in the district of Ravenna, at the mouth of a great arm of the Po, was, so early as the com-

mencement of our era, eleven Italian miles distant from the sea.*

The greatest depth of the Adriatic, between Dalmatia and the mouths of the Po, is twenty-two fathoms; but a large part of the Gulf of Trieste and the Adriatic, opposite Venice, is less than twelve fathoms deep. Farther to the south, where it is less affected by the influx of great rivers, the gulf deepens considerably. Donati, after dredging the bottom, discovered the new deposits to consist partly of mud and partly of rock, the latter formed of calcareous matter, encrusting shells. He also ascertained, that particular species of testacea were grouped together in certain places, and were becoming slowly incorporated with the mud, or calcareous precipitates.† Olivi, also, found some deposits of sand, and others of mud, extending half way across the gulf; and he states that their distribution along the bottom was evidently determined by the prevailing current.‡ It is probable, therefore, that the finer sediment of all the rivers at the head of the Adriatic may be intermingled by the influence of the current; and all the central parts of the gulf may be considered as slowly filling up with horizontal deposits, precisely similar to those of the Subapennine hills, and containing many of the same species of shells. The Po merely introduces at present fine sand and mud, for it carries no pebbles farther than the spot where it joins the Trebia, west of Piacenza. Near the northern borders of the basin, the Isonzo, Taglia-

* See Brocchi on the various writers on this subject. *Conch. Foss. Subap.*, vol. i. p. 118.

† *Ibid.*, vol. i. p. 39.

‡ *Ibid.*, vol. ii. p. 94.

mento, and many other streams, are forming immense beds of sand and some conglomerate, for here some high mountains of Alpine limestone approach within a few miles of the sea.

In the time of the Romans, the hot-baths of Monfalcone were on one of several islands of Alpine limestone, between which and the mainland, on the north, was a channel of the sea, about a mile broad. This channel is now converted into a grassy plain, which surrounds the islands on all sides. Among the numerous changes on this coast, we find that the present channel of the Isonzo is several miles to the west of its ancient bed, in part of which, at Ronchi, the old Roman bridge which crossed the Via Appia was lately found buried in fluvial silt.

Notwithstanding the present shallowness of the Adriatic, it is highly probable that its original depth was very great; for if all the low alluvial tracts were taken away from its borders and replaced by sea, the high land would terminate in that abrupt manner which generally indicates, in the Mediterranean, a great depth of water near the shore, except in those spots where sediment imported by rivers and currents has diminished the depth. Many parts of the Mediterranean are now ascertained to be above two thousand feet deep, close to the shore, as between Nice and Genoa; and even sometimes six thousand feet, as near Gibraltar. When, therefore, we find, near Parma, and in other districts in the interior of the peninsula, beds of horizontal tertiary marl attaining a thickness of about two thousand feet, or when we discover strata of inclined conglomerate, of the same age, near Nice, measuring above a thousand feet in thickness, and extending seven or eight miles in length, we behold

nothing which the analogy of the deltas in the Adriatic might not lead us to anticipate.

Delta of the Nile.—That Egypt was “the gift of the Nile,” was the opinion of her priests before the time of Herodotus; but we have no authentic memorials for determining, with accuracy, the additions made from time to time to the habitable surface of that country. We know that the base of the delta has been considerably modified since the days of Homer. The ancient geographers mention seven principal mouths of the Nile, of which the most eastern, the Pelusian, has been entirely silted up, and the Mendesian, or Tanitic, has disappeared. The Phatnitic mouth, and the Sebenitic, have been so altered, that the country immediately about them has little resemblance to that described by the ancients. The Bolbitine mouth has increased in its dimensions, so as to cause the city of Rosetta to be at some distance from the sea.

But the alterations produced round the Canopic mouth are the most important. The city Foah, which, so late as the beginning of the fifteenth century, was on this embouchure, is now more than a mile inland. Canopus, which, in the time of Scylax, was a desolate insular rock, has been connected with the firm land; and Pharos, an island in times of old, now belongs to the continent. Homer says, its distance from Egypt was one day’s voyage by sea.* That this should have been the case in Homer’s time, Larcher and others have, with reason, affirmed to be in the highest degree improbable; but Strabo has judiciously anticipated their objections, observing, that Homer was

* Odys., book iv. v. 355.

probably acquainted with the gradual advance of the land on this coast, and availed himself of this phenomenon to give an air of higher antiquity to the remote period in which he laid the scene of his poem.* The Lake Mareotis, also, together with the canal which connected it with the Canopic arm of the Nile, has been filled with mud, and is become dry. Herodotus observes, “ that the country round Memphis seemed formerly to have been an arm of the sea gradually filled by the Nile, in the same manner as the Meander, Achelous, and other streams, had formed deltas. Egypt, therefore, he says, like the Red Sea, was once a long narrow bay, and both gulfs were separated by a small neck of land. If the Nile, he adds, should by any means have an issue into the Arabian Gulf, it might choke it up with earth in twenty thousand, or even, perhaps, in ten thousand years; and why may not the Nile have filled with mud a still greater gulf in the space of time which has passed before our age?”†

Mud of the Nile.—The analysis of the mud of the Nile gives nearly one half of argillaceous earth, and about one fourth of carbonate of lime, the remainder consisting of water, oxide of iron, and carbonate of magnesia.‡

The depth of the Mediterranean is about twelve fathoms at a small distance from the shore of the delta; it afterwards increases gradually to 50, and then suddenly descends to 380 fathoms, which is, perhaps, the original depth of the sea where it has not been

* Lib. I. Part i. pp. 80. and 98. Consult Von Hoff, vol. i. p. 244.

† Euterpe, XI.

‡ Girard, *Mém. sur l’Egypte*, tome i. pp. 348. 382.

rendered shallower by fluvial matter. The progress of the delta in the last two thousand years affords, perhaps, no measure for estimating its rate of growth when it was an inland bay, and had not yet protruded itself beyond the coast-line of the Mediterranean. A powerful current now sweeps along the shores of Africa, from the Straits of Gibraltar to the prominent convexity of Egypt, the western side of which is continually the prey of the waves ; so that not only are fresh accessions of land checked, but ancient parts of the delta are carried away. By this cause Canopus and some other towns have been overwhelmed ; but to this subject I shall again refer when speaking of tides and currents.

CHAPTER V.

OCEANIC DELTAS.

Oceanic deltas — Deltas of the Ganges and Burrampooter — Its size — Rate of advance, and nature of its deposits — Formation and destruction of islands — Abundance of crocodiles — Inundations — Delta of the Mississippi — Deposits of drift wood — Gradual filling up of the Yellow Sea — Estimate of the quantity of mud carried down by the Ganges — Formation of valleys illustrated by the growth of deltas — Grouping of new strata in general — Convergence of deltas — Conglomerates — Various causes of stratification — Direction of laminæ — Remarks on the interchange of land and sea.

THE remaining class of deltas are those in which rivers, on entering the sea, are exposed to the influence of the tides. In this case it frequently happens that an estuary is produced, or negative delta, as Rennell termed it, where, instead of any encroachment of the land upon the sea, the ocean enters the river's mouth, and penetrates into the land beyond the general coastline. Where this happens, the tides and currents are the predominating agents in the distribution of transported sediment. The phenomena, therefore, of such estuaries, will be treated of when the movements of the ocean come under consideration. But whenever the volume of fresh water is so great as to counteract and almost neutralize the force of tides and currents, and in all cases where these agents have not sufficient power to remove to a distance the whole of the sediment periodically brought down by rivers, oceanic

deltas are produced. Of these, I shall now select a few illustrative examples.

Delta of the Ganges. — The Ganges and the Burrampooter descend, from the highest mountains in the world, into a gulf which runs 225 miles into the continent. The Burrampooter is somewhat the larger river of the two, but it first takes the name of the Megna, when joined by a smaller stream so called, and afterwards loses this second name on its union with the Ganges, at the distance of about forty miles from the sea. The area of the delta of the Ganges (without including that of the Burrampooter, which has now become conterminous) is considerably more than double that of the Nile ; and its head commences at a distance of 220 miles, in a direct line from the sea. Its base is two hundred miles in length, including the space occupied by the two great arms of the Ganges which bound it on either side. That part of the delta which borders on the sea is composed of a labyrinth of rivers and creeks, all filled with salt water, except those immediately communicating with the principal arm of the Ganges. This tract alone, known by the name of the Woods, or Sunderbunds, a wilderness infested by tigers and alligators, is, according to Rennell, equal in extent to the whole principality of Wales.*

On the sea-coast there are eight great openings, each of which has evidently, at some ancient period, served in its turn as the principal channel of discharge. Although the flux and reflux of the tide extend even to the head of the delta, when the river is low, yet, when it is periodically swollen by tropical rains, the velocity

* Account of the Ganges and Burrampooter Rivers, by Major Rennell, Phil. Trans. 1781.

of the stream counteracts the tidal current, so that, except very near the sea, the ebb and flow become insensible. During the flood season, therefore, the Ganges almost assumes the character of a river entering a lake or inland sea; the movements of the ocean being then subordinate to the force of the river, and only slightly disturbing its operations. The great gain of the delta in height and area takes place during the inundations; and during other seasons of the year, the ocean makes reprisals, scouring out the channels, and sometimes devouring rich alluvial plains.

So great is the quantity of mud and sand poured by the Ganges into the gulf in the flood season, that the sea only recovers its transparency at the distance of sixty miles from the coast. The general slope, therefore, of the new strata must be extremely gradual. By the charts recently published, it appears that there is a gradual deepening from four to about sixty fathoms, as we proceed from the base of the delta to the distance of about one hundred miles into the Bay of Bengal. At some few points seventy, or even one hundred fathoms, are obtained at that distance.

One remarkable exception, however, occurs to the regularity of the shape of the bottom; for, opposite the middle of the delta, at the distance of thirty or forty miles from the coast, is a nearly circular space called the "swatch of no ground," about fifteen miles in diameter, where soundings of 100, and even 130 fathoms, fail to reach the bottom. This phenomenon is the more extraordinary, since the depression occurs within five miles of the line of shoals; and not only do the waters charged with Gangetic sediment pass over it continually, but, during the monsoons, the sea, loaded with mud and sand, is beaten back in that direction

towards the delta. As the mud is known to extend for eighty miles farther into the gulf, we may be assured that, in the course of ages, the accumulation of strata in "the swatch" has been of enormous thickness; and we seem entitled to deduce, from the present depth at the spot, that the original inequalities of the bottom of the Bay of Bengal were on as grand a scale as are those of the main ocean.

Opposite the mouth of the Hoogly river, and immediately south of Sager Island, four miles from the nearest land of the delta, a new isle was formed about thirty years ago, called Edmonston Island, where there is a lighthouse. The isle has been for many years covered with vegetation and shrubs, but the whole surface was submerged for some hours during the late inundation of May, 1833, the light-keepers having only escaped by ascending into the lantern. By this flood the dimensions of the isle were considerably diminished. Although there is evidence of gain at some points, the general progress of the coast is very slow; for the tides, which rise from thirteen to sixteen feet, are actively employed in removing the alluvial matter, and diffusing it over a wide area.* The new strata consist entirely of sand and fine mud; such, at least, are the only materials which are exposed to view in regular beds on the

* It is stated in the chart published in the year 1825, by Captain Horsburgh, that the sands opposite the whole delta stretched between four and five miles farther south than they had done forty years previously; and this was taken as the measure of the progress of the delta itself, during the same period. But a more careful comparison of the ancient charts, during a recent survey, has proved that they were extremely incorrect in their latitudes, so that the advance of the sands and delta was greatly exaggerated.

banks of the numerous creeks. No substance so coarse as gravel occurs in any part of the delta, nor nearer the sea than 400 miles. It should be observed, however, that the superficial alluvial beds, which are thrown down rapidly from turbid waters during the floods, may be very distinct from those deposited at a greater distance from the shore, where crystalline precipitates, perhaps, are forming, on the evaporation of so great a surface, exposed to the rays of a tropical sun. The separation of sand and other matter, held in mechanical suspension, may take place where the waters are in motion; but mineral ingredients, held in chemical solution, would naturally be carried to a greater distance, where they may aid in the formation of corals and shells, and, in part, perhaps, become the cementing principle of rocky masses.

A well was sunk at Fort William, Calcutta, in the hope of obtaining water, through beds of adhesive clay, to the depth of 146 feet. A bed of yellow sand was then entered, and at the depth of 152 feet another stratum of clay.*

Islands formed and destroyed. — Major R. H. Colebrooke, in his account of the course of the Ganges River, relates examples of the rapid filling up of some of its branches, and the excavation of new channels, where the number of square miles of soil removed in a short time (the column of earth being 114 feet high) was truly astonishing. Forty square miles, or 25,600 acres are mentioned as having been carried away, in one locality, in the course of a few years.† The immense transportation of earthy matter by the Ganges

* See India Gazette, June 9., 1831.

† Trans. of the Asiatic Society, vol. vii. p. 14.

and Megna is proved by the great magnitude of the islands formed in their channels during a period far short of that of a man's life. Some of these, many miles in extent, have originated in large sand-banks thrown up round the points at the angular turning of the river, and afterwards insulated by breaches of the stream. Others, formed in the main channel, are caused by some obstruction at the bottom. A large tree, or a sunken boat, is sometimes sufficient to check the current, and cause a deposit of sand, which accumulates till it usurps a considerable portion of the channel. The river then borrows on each side to supply the deficiency in its bed, and the island is afterwards raised by fresh deposits during every flood. In the great gulf below Luckipour, formed by the united waters of the Ganges and Burrampooter (or Megna), some of the islands, says Rennell, rival in size and fertility the Isle of Wight. While the river is forming new islands in one part, it is sweeping away old ones in others. Those newly formed are soon overrun with reeds, long grass, the *Tamarix Indica*, and other shrubs, forming impenetrable thickets, where tigers, buffaloes, deer, and other wild animals, take shelter. It is easy, therefore, to perceive, that both animal and vegetable remains must continually be precipitated into the flood, and sometimes become imbedded in the sediment which subsides in the delta.

Two species of crocodiles, of distinct genera, abound in the Ganges and its tributary and contiguous waters; and Mr. H. T. Colebrooke informs me, that he has seen both kinds in places far inland, many hundred miles from the sea. The Gangetic crocodile, or Gavial (in correct orthography, Garial), is confined to the fresh water, but the common crocodile frequents

both fresh and salt ; being much larger and fiercer in salt and brackish water. These animals swarm in the brackish water along the line of sand-banks where the advance of the delta is most rapid. Hundreds of them are seen together in the creeks of the delta, or basking in the sun on the shoals without. They will attack men and cattle, destroying the natives when bathing, and tame and wild animals which come to drink. "I have not unfrequently," says Mr. Colebrooke, "been witness to the horrid spectacle of a floating corpse seized by a crocodile with such avidity, that he half emerged above the water with his prey in his mouth." The geologist will not fail to observe how peculiarly the habits and distribution of these saurians expose them to become imbedded in the horizontal strata of fine mud which are annually deposited over many hundred square miles in the Bay of Bengal. The inhabitants of the land, which happen to be drowned or thrown into the water, are usually devoured by these voracious reptiles ; but we may suppose the remains of the saurians themselves to be continually entombed in the new formations.

Inundations.—It sometimes happens, at the season when the periodical flood is at its height, that a strong gale of wind, conspiring with a high spring-tide, checks the descending current of the river, and gives rise to most destructive inundations. From this cause, in the year 1763, the waters at Luckipour rose six feet above their ordinary level, and the inhabitants of a considerable district, with their houses and cattle, were totally swept away.

The population of all oceanic deltas are particularly exposed to suffer by such catastrophes, recurring at considerable intervals of time ; and we may safely

assume, that such tragical events have happened again and again since the Gangetic delta was inhabited by man. If human experience and forethought cannot always guard against these calamities, still less can the inferior animals avoid them; and the monuments of such disastrous inundations must be looked for in great abundance in strata of all ages, if the surface of our planet has always been governed by the same laws. When we reflect on the general order and tranquillity that reigns in the rich and populous delta of Bengal, notwithstanding the havoc occasionally committed by the depredations of the ocean, we perceive how unnecessary it is to attribute the imbedding of successive races of animals in older strata to extraordinary energy in the causes of decay and reproduction in the infancy of our planet, or to those general catastrophes and sudden revolutions resorted to by some theorists.

Delta of the Mississippi. — As the delta of the Ganges may be considered a type of those formed on the borders of the ocean, it will be unnecessary to accumulate examples of others on a no less magnificent scale, as, for example, at the mouths of the Orinoco and Amazon. To these, however, I shall revert by and by, when treating of the agency of currents. The tides in the Mexican Gulf are so feeble, that the delta of the Mississippi has somewhat of an intermediate character between an oceanic and mediterranean delta. A long narrow tongue of land is protruded, consisting simply of the banks of the river, wearing precisely the same appearance as in the inland plains during the periodical inundations, when nothing appears above water but the higher part of the sloping glacis before described.* This tongue of land has advanced many

* Chapter II.

leagues since New Orleans was built. Great submarine deposits are also in progress, stretching far and wide over the bottom of the sea, which has become extremely shallow, not exceeding ten fathoms in depth. Opposite the mouth of the Mississippi large rafts of drift trees, brought down every spring, are matted together into a net-work many yards in thickness, and stretching over hundreds of square leagues.* They afterwards become covered over with a fine mud, on which other layers of trees are deposited the year following, until numerous alternations of earthy and vegetable matter are accumulated.

Alternation of deposits. — An observation of Darby, in regard to the strata composing part of this delta, deserves attention. In the steep banks of the Atchafalaya, an arm of the Mississippi before alluded to in our description of “the raft,” the following section is observable at low water:—first, an upper stratum, consisting invariably of blueish clay, common to the banks of the Mississippi; below this a stratum of red ochreous earth, peculiar to Red River, under which the blue clay of the Mississippi again appears†; and this arrangement is constant, proving, as that geographer remarks, that the waters of the Mississippi and the Red River occupied alternately, at some former periods, considerable tracts below their present point of union. Such alternations are probably common in submarine spaces situated between two converging deltas; for, before the two rivers unite, there must almost always be a certain period when an intermediate tract will by turns be occupied and abandoned by the

* Captain Hall's Travels in North America, vol. iii. p. 338.

Darby's Louisiana, p. 103.

waters of each stream ; since it can rarely happen that the season of highest flood will precisely correspond in each. In the case of the Red River and Mississippi, which carry off the waters from countries placed under widely distant latitudes, an exact coincidence in the time of greatest inundation is very improbable.

CONCLUDING REMARKS ON DELTAS.

Quantity of sediment in river water.—Very few satisfactory experiments have as yet been made, to enable us to determine, with any degree of accuracy, the mean quantity of earthy matter discharged annually into the sea by some one of the principal rivers of the earth. Hartsoeker computed the Rhine to contain in suspension, when most flooded, one part in a hundred of mud in volume* ; but it appears from experiments recently made by Mr. Leonard Horner, at Bonn, that $\frac{1}{1000}$ th would have been a nearer approximation to the truth. Sir George Staunton inferred from several observations, that the water of the Yellow River in China contained earthy matter in the proportion of one part to two hundred, and he calculated that it brought down in a single hour two million cubic feet of earth, or forty-eight million daily ; so that, if the Yellow Sea be taken to be 120 feet deep, it would require seventy days for the river to convert an English square mile into firm land, and 24,000 years to turn the whole sea into terra firma, assuming it to be 125,000 square miles in area.† Manfredi, the cele-

* Comment. Bonon., vol. ii. part i. p. 237.

† Staunton's Embassy to China, London, 1797, 4to. vol. ii. p. 408.

brated Italian hydrographer, conceived the average proportion of sediment in all the running water on the globe, which reached the sea, to be $\frac{1}{175}$, and he imagined that it would require a thousand years for the sediment carried down to raise the general level of the sea about one foot. Some writers, on the contrary, as De Maillet, have declared the most turbid waters to contain far less sediment than any of the above estimates would import. One of the most extraordinary statements is that of Major Rennell, in his excellent paper, before referred to, on the delta of the Ganges. "A glass of water," he says, "taken out of this river when at its height, yields about one part in four of mud. No wonder, then," he adds, "that the subsiding waters should quickly form a stratum of earth, or that the delta should encroach on the sea!"*

There must certainly be some mistake, perhaps a misprint, in the statement in the *Phil. Trans.*; and some have conjectured that the learned hydrographer meant one part in four hundred of mud. In former editions of this work, I expressed my regret that so much inconsistency and contradiction should be found in the statements and speculations relative to this interesting subject; and I endeavoured to point out the high geological importance of reducing to arithmetical computation the aggregate amount of solid matter transported by certain large rivers to the sea. The deficiency of data has now been, in some degree, removed by the labours of Mr. Everest, who has instituted a series of observations "On the earthy matter brought down by the Ganges" at Ghazipur, above Calcutta. †

* *Phil. Trans.* 1781.

† *Journ. of Asiatic Soc.* No. 6. p. 238. June, 1832. See also Mr. Prinsep, *Gleanings in Science*, vol. iii. p. 185.

The first step to be made in all such calculations is to ascertain the average volume of water passing annually down the channel of a river. This might easily be accomplished if the breadth, depth, and velocity of a stream were constant and uniform throughout the year; but as all these conditions are liable to vary according to the seasons, the problem becomes extremely complex. In the Ganges, as in other rivers in hot climates, there are periodical inundations, during which by far the greatest part of the annual discharge takes place, and the most important point, therefore, to determine, is the mean breadth, depth, and velocity of the stream during this period.

Mr. Everest found that, in 1831, the number of cubic feet of water discharged by the Ganges per second was, during the

Rains, (4 months)	-	-	494,208
Winter, (5 months)	-	-	71,200
Hot weather, (3 months)	-	-	36,330

so that we may state in round numbers, that 500,000 cubic feet flow down during the four months of the flood season, from June to September, and only 100,000 during the remaining eight months.

Having obtained the volume of water, we have next to inquire what is the proportion of solid matter contained in it; and for this purpose, a definite quantity, as, for example, a quart, is taken from the river on different days, sometimes from the middle of the current, and sometimes nearer the banks. This water is then evaporated, the solid residuum weighed, and the mean quantity of sediment thus ascertained, throughout the rainy season. The same observations

must then be repeated for the other portions of the year.

In computing the quantity of water, Mr. Everest made no allowance for the decreased velocity of the stream near the bottom, presuming that it is compensated by the increased weight of matter held in suspension there. We think it probable that the amount of sediment is by no means exaggerated by this circumstance; but rather under-rated, as the heavier grains of sand, which can never rise into the higher parts of the stream, are drifted along the bottom.

Now the average quantity of solid matter suspended in the water during the rains was, by weight, $\frac{1}{428}$ th part; but as the water is about one half the specific gravity of the dried mud, the solid matter discharged is $\frac{1}{856}$ th part in bulk, or 577 cubic feet per second. This gives a total of 6,082,041,600 cubic feet for the discharge in the 122 days of the rain. The proportion of sediment in the waters at other seasons was comparatively insignificant, the total amount during the five winter months being only 247,881,600 cubic feet, and during the three months of hot weather, 38,154,240 cubic feet. The total annual discharge, then, would be 6,368,077,440 cubic feet.

In order to give some idea of the magnitude of this result, we will assume that the specific gravity of the dried mud is only one half that of granite (it would, however, be more); in that case, the earthy matter discharged in a year would equal 3,184,038,720 cubic feet of granite. Now about $12\frac{1}{2}$ cubic feet of granite weigh one ton, and it is computed that the great Pyramid of Egypt, if it were a solid mass of granite, would weigh about 6,000,000 tons. The mass of matter, therefore, carried down annually, would, ac-

according to this estimate, more than equal in weight and bulk forty-two of the great Pyramids of Egypt, and that borne down in the four months of the rains would equal forty pyramids. But if, without any conjecture as to what may have been the specific gravity of the mud, we attend merely to the weight of solid matter actually proved by Mr. Everest to have been contained in the water, we find that the number of tons weight which passed down in the 122 days of the rainy season was 339,413,760, which would give the weight of fifty-six pyramids and a half; and in the whole year 6,368,077,440 tons, or nearly the weight of sixty pyramids.

The base of the great Pyramid of Egypt covers eleven acres, and its perpendicular height is about five hundred feet. It is scarcely possible to present any picture to the mind which will convey an adequate conception of the mighty scale of this operation, so tranquilly and almost insensibly carried on by the Ganges, as it glides through its alluvial plain. It may, however, be stated, that if a fleet of more than eighty Indiamen, each freighted with about 1400 tons weight of mud, were to sail down the river every hour of every day and night for four months continuously, they would only transport from the higher country to the sea a mass of solid matter equal to that borne down by the Ganges in the flood season. Or the exertions of a fleet of about 2000 such ships going down daily with the same burden, and discharging it into the gulf, would be no more than equivalent to the operations of the great river. Yet it is probable that the Burrampooter conveys annually as much solid matter to the sea as the Ganges.

The most voluminous current of lava which has

flowed from Etna within historical times was that of 1669. Ferrara, after correcting Borrelli's estimate, calculated the quantity of cubic yards of lava in this current at 140,000,000. Now, this would not equal in bulk one fifth of the sedimentary matter which is carried down in a single year by the Ganges, according to the estimate above explained; so that it would require five grand eruptions of Etna to transfer a mass of lava from the subterranean regions to the surface equal in volume to the mud carried down to the sea in the same time by one river in Bengal.

Grouping of Strata in Deltas.—The changes which have taken place in deltas, even since the times of history, may suggest many important considerations in regard to the manner in which subaqueous sediment is distributed. Notwithstanding frequent exceptions arising from the interference of a variety of causes, there are some general laws of arrangement which must evidently hold good in almost all the lakes and seas now filling up. If a lake, for example, be encircled on two sides by lofty mountains, receiving from them many rivers and torrents of different sizes, and if it be bounded on the other sides, where the surplus waters issue, by a comparatively low country, it is not difficult to define some of the leading geological features which must characterize the lacustrine formation when this basin shall have been gradually converted into dry land by the influx of sediment. The strata would be divisible into two principal groups: the *older* comprising those deposits which originated on the side adjoining the mountains, where numerous deltas first began to form; and the *newer* group consisting of beds deposited in the more central parts of the basin, and towards the side farthest from the

mountains. The following characters would form the principal marks of distinction between the strata in each series. The more ancient system would be composed, for the most part, of coarser materials, containing many beds of pebbles and sand often of great thickness, and sometimes dipping at a considerable angle. These, with associated beds of finer ingredients, would, if traced round the borders of the basin, be seen to vary greatly in colour and mineral composition, and would also be very irregular in thickness. The beds, on the contrary, in the newer group, would consist of finer particles, and would be horizontal, or very slightly inclined. Their colour and mineral composition would be very homogeneous throughout large areas, and would differ from almost all the separate beds in the older series.

The following causes would produce the diversity here alluded to between the two great members of such lacustrine formations:—When the rivers and torrents first reach the edge of the lake, the detritus washed down by them from the adjoining heights sinks at once into deep water, all the heavier pebbles and sand subsiding near the shore. The finer mud is carried somewhat farther out, but not to the distance of many miles, for the greater part may be seen, as, for example, where the Rhone enters the Lake of Geneva, to fall down in clouds to the bottom not far from the river's mouth. Thus alluvial tracts are soon formed at the mouths of every torrent and river, and many of these in the course of ages become of considerable extent. Pebbles and sand are then transported farther from the mountains; but in their passage they decrease in size by attrition, and are in part converted into mud and sand. At length some of the numerous deltas

which are all directed towards a common centre approach near to each other — those of adjoining torrents become united, and each is merged, in its turn, in the delta of the largest river, which advances most rapidly into the lake, and renders all the minor streams, one after the other, its tributaries. The various mineral ingredients of all are thus blended together into one homogeneous mixture, and the sediment is poured out from a common channel into the lake.

As the average size of the transported particles decreases, while the force and volume of the current augments, the newer deposits are diffused continually over a wider area, and are consequently more horizontal than the older. When at first there were many independent deltas near the borders of the basin, their separate deposits differed entirely from each other; one may have been charged, like the Arve where it joins the Rhone, with white sand, and sediment derived from granite — another may have been black, like many streams in the Tyrol, flowing from the waste of decomposing rocks of dark slate — a third may have been coloured by ochreous sediment, like the Red River in Louisiana — a fourth, like the Elsa in Tuscany, may have held much carbonate of lime in solution. At first they would each form distinct deposits of sand, gravel, limestone, marl, or other materials; but after their junction new chemical combinations and a distinct colour would be the result, and the particles, having been conveyed ten, twenty, or a greater number of miles over alluvial plains, would become finer.

In deltas where the causes are more complicated, and where tides and currents partially interfere, the above description would only be applicable, with certain

modifications ; but if a series of earthquakes accompany the growth of a delta, and change the levels of the land from time to time, as in the region where the Indus now enters the sea, and others hereafter to be mentioned, the phenomena will then depart still more widely from the ordinary type.

Convergence of Deltas. — If we possessed an accurate series of maps of the Adriatic for many thousand years, our retrospect would, without doubt, carry us gradually back to the time when the number of rivers descending from the mountains into that gulf by independent deltas was far greater in number. The deltas of the Po and the Adige, for instance, would separate themselves within the *recent* era, as, in all probability, would those of the Isonzo and the Torre. If, on the other hand, we speculate on future changes, we may anticipate the period when the number of deltas will greatly diminish ; for the Po cannot continue to encroach at the rate of a mile in a hundred years, and other rivers to gain as much in six or seven centuries upon the shallow gulf, without new junctions occurring from time to time, so that Eridanus, “ the king of rivers,” will continually boast a greater number of tributaries. The Ganges and Burrampooter have probably become confluent within the historical era ; and the date of the junction of the Red River and the Mississippi would, in all likelihood, have been known if America had not been so recently discovered. The union of the Tigris and the Euphrates must undoubtedly have been one of the modern geographical changes on our earth, and similar remarks might be extended to many other regions.

Formation of Conglomerates. — Along the base of the Maritime Alps, between Toulon and Genoa, the

rivers, with few exceptions, are now forming strata of conglomerate and sand. Their channels are often several miles in breadth, some of them being dry, and the rest easily forded for nearly eight months in the year, whereas during the melting of the snow they are swollen, and a great transportation of mud and pebbles takes place. In order to keep open the main road from France to Italy, now carried along the sea-coast, it is necessary to remove annually great masses of shingle brought down during the flood-season. A portion of the pebbles are seen in some localities, as near Nice, to form beds of shingle along the shore, but the greater part are swept into a deep sea. The small progress made by the deltas of minor rivers on this coast need not surprise us, when we recollect that there is sometimes a depth of two thousand feet at a few hundred yards from the beach, as near Nice. Similar observations might be made respecting a large proportion of the rivers in Sicily, and, among others, respecting that which, immediately north of the port of Messina, hurries annually vast masses of granitic pebbles into the sea.

When the deltas of rivers, having many mouths, converge, a partial union at first takes place by the confluence of some one or more of their arms; but it is not until the main trunks are connected above the head of the common delta that a complete intermixture of their joint waters and sediment takes place. The union, therefore, of the Po and Adige, and of the Ganges and Burrampooter, is still incomplete. If we reflect on the geographical extent of surface drained by rivers such as now enter the bay of Bengal, and then consider how complete the blending together of the greater part of their transported matter has already

become, and throughout how vast a delta it is spread by numerous arms, we no longer feel so much surprise at the area occupied by some ancient formations of homogeneous mineral composition. But our surprise will be still further lessened when we afterwards inquire into the action of tides and currents, in disseminating sediment.*

Causes of Stratification in Deltas.—That the matter carried by rivers into seas and lakes is not thrown in confused and promiscuous heaps, but is spread out far and wide along the bottom, is well ascertained; and that it must for the most part be divided into distinct strata, may in part be inferred where it cannot be proved by observation. The horizontal arrangement of the strata, when laid open to the depth of twenty or thirty feet in the deltas of the Ganges, Indus, and Mississippi, is alluded to by many writers; and the same disposition is well known to obtain in all modern deposits of lakes and estuaries.

Natural divisions are often occasioned by the interval of time which separates annually the deposition of matter during the periodical rains, or melting of the snow upon the mountains. The deposit of each year acquires some degree of consistency before that of the succeeding year is superimposed. A variety of circumstances also give rise annually, or sometimes from day to day, to slight variations in colour, fineness of the particles, and other characters, by which alternations of strata distinct in texture, and mineral ingredients, are produced. Thus, for example, at one period of the year, drift wood may be carried down, and at another mud, as was before stated to be the case in the delta of the Mississippi; or at one time when

* See Chap. VIII.

the volume and velocity of the stream are greatest, pebbles and sand may be spread over a certain area, over which, when the waters are low, fine matter or chemical precipitates are formed. During inundations the current of fresh water often repels the sea for many miles; but when the river is low, salt water again occupies the same space. When two deltas are converging, the intermediate space is often, for reasons before explained, alternately the receptacle of different sediments derived from the converging streams. The one is, perhaps, charged with calcareous, the other with argillaceous matter; or one sweeps down sand and pebbles, the other impalpable mud. These differences may be repeated, with considerable regularity, until a thickness of hundreds of feet of alternating beds is accumulated. The multiplication, also, of shells and corals in particular spots, must give rise occasionally to lines of separation, and divide a mass which might otherwise be homogeneous into distinct strata.

An examination of the shell marl now forming in the Scotch lakes, or the sediment termed "warp," which subsides from the muddy water of the Humber, and other rivers, shows that recent deposits are often composed of a great number of extremely thin layers, either even or slightly undulating, and preserving a general parallelism to the planes of stratification. Sometimes, however, the laminæ in modern strata are disposed diagonally at a considerable angle, which appears to take place where there are conflicting movements in the waters. In January, 1829, I visited, in company with Professor L. A. Necker, of Geneva, the confluence of the Rhone and Arve, when those rivers were very low, and were cutting channels

through the vast heaps of debris thrown down from the waters of the Arve, in the preceding spring. One of the sand-banks which had formed, in the spring of 1828, where the opposing currents of the two rivers neutralized each other, and caused a retardation in the motion, had been undermined; and the following is an exact representation of the arrangement of laminae exposed in a vertical section. The length of the portion here seen is about twelve feet, and the height five. The strata A A consist of irregular alternations of pebbles and sand in undulating beds: below these are seams of very fine sand B B, some as thin as paper, others about a quarter of an inch thick. The strata C C are composed of layers of fine greenish-gray sand, as thin as paper. Some of the inclined beds will be seen to be thicker at their upper, others at their

No. 7.

Section on the banks of the Arve at its confluence with the Rhone, showing the stratification of deposits where currents meet.

lower extremity, the inclination of some being very considerable. These layers must have accumulated one on the other by lateral apposition, probably when one of the rivers was very gradually increasing or

diminishing in velocity, so that the point of greatest retardation caused by their conflicting currents shifted slowly, allowing the sediment to be thrown down in successive layers on a sloping bank. The same phenomenon is exhibited in older strata of all ages; and when they are treated of, I shall endeavour more fully to illustrate the origin of such a structure.

Constant interchange of Land and Sea. — I may here conclude my remarks on deltas, observing that, imperfect as is our information of the changes which they have undergone within the last three thousand years, they are sufficient to show how constant an interchange of sea and land is taking place on the face of our globe. In the Mediterranean alone, many flourishing inland towns, and a still greater number of ports, now stand where the sea rolled its waves since the era of the early civilization of Europe. If we could compare with equal accuracy the ancient and actual state of all the islands and continents, we should probably discover that millions of our race are now supported by lands situated where deep seas prevailed in earlier ages. In many districts not yet occupied by man, land animals and forests now abound where the anchor once sunk into the oozy bottom. We shall find, on inquiry, that inroads of the ocean have been no less considerable; and when to these revolutions, produced by aqueous causes, we add analogous changes wrought by igneous agency, we shall, perhaps, acknowledge the justice of the conclusion of a great philosopher of antiquity, when he declared that the whole land and sea on our globe periodically changed places.*

* See above, book i. p. 21.

CHAPTER VI.

DESTROYING AND TRANSPORTING EFFECTS OF TIDES AND CURRENTS.

Destroying and transporting effects of tides and currents — Differences in the rise of the tides — Velocity of currents — Causes of currents — Action of the sea on the British coast — Shetland Islands — Large blocks removed — Effects of lightning — Breach caused in a mass of porphyry — Isles reduced to clusters of rocks. — Orkney Isles — East coast of Scotland — Stones thrown up on the Bell Rock — East coast of England — Waste of the cliffs of Holderness, Norfolk, and Suffolk — Silting up of estuaries — Origin of submarine forests — Yarmouth estuary — Submarine forests — Suffolk coast — Dunwich — Essex coast — Estuary of the Thames — Goodwin Sands — Coast of Kent — Formation of Straits of Dover — South coast of England — Coast of Sussex — Coast of Hants — Coast of Dorset — Portland — Origin of the Chesil Bank — Cornwall — Lionesse tradition — Coast of Brittany.

ALTHOUGH the movements of great bodies of water, termed tides and currents, are in general due to very distinct causes, their effects cannot be studied separately, for they produce, by their joint action, those changes which are objects of geological interest. These forces may be viewed in the same manner as we before considered rivers, first, as employed in destroying portions of the solid crust of the earth, and removing them to other localities; secondly, as reproductive of new strata.

Tides.—It would be superfluous at the present day to offer any remarks on the cause of the tides. They are not perceptible in lakes, or in most inland seas; in the Mediterranean even, deep and extensive as is that sea, they are scarcely sensible to ordinary observation, their effects being quite subordinate to those of the winds and currents. In some localities, however, as in the Straits of Messina, there is an ebb and flow to the amount of two feet and upwards, at Naples and at the Euripus of twelve or thirteen inches, and at Venice, according to Rennell, of five feet.* In the Syrtes, also, of the ancients, two wide shallow gulfs which penetrate very far within the northern coast of Africa, between Carthage and Cyrene, the rise is said to exceed five feet.†

In islands remote from any continent, the ebb and flow of the ocean is very slight, as at St. Helena, for example, where it is rarely above three feet.‡ In any given line of coast, the tides are greatest in narrow channels, bays, and estuaries, and least in the intervening tracts where the land is prominent. Thus, at the entrance of the estuary of the Thames and Medway, the rise of the spring-tides is eighteen feet; but when we follow our eastern coast from thence northward, towards Lowestoff and Yarmouth, we find a gradual diminution, until, at the places last mentioned, the highest rise is only seven or eight feet. From this point there begins again to be an increase, so that at Cromer, where the coast again retires towards the west, the

* Geography of Herodotus, vol. ii. p. 331.

† Ibid. p. 328.

‡ Romme, Vents et Courans, vol. ii. p. 2. Rev. F. Fallows, Quart. Journ. of Science, March, 1829.

rise is sixteen feet, and towards the extremity of the gulf called "the Wash," as at Lynn and in Boston deeps, it is from twenty-two to twenty-four feet, and in some extraordinary cases twenty-six feet. From thence again there is a decrease towards the north, the elevation at the Spurn Point being from nineteen to twenty feet, and at Flamborough Head and the Yorkshire coast from fourteen to sixteen feet.*

At Milford Haven in Pembrokeshire, at the mouth of the Bristol Channel, the tides rise thirty-six feet, and at King-Road near Bristol forty-two feet. At Chepstow on the Wye, a small river which opens into the estuary of the Severn, they reach fifty feet, and sometimes sixty-nine, and even seventy-two feet.† A current which sets in on the French coast, to the west of Cape La Hague, becomes pent up by Guernsey, Jersey, and other islands, till the rise of the tide is from twenty to forty-five feet, which last height it attains at Jersey, and at St. Malo, a seaport of Brittany.

Currents.—The most extensive and best determined of all currents is that which in one part of its course is called the Gulf stream. It first sets westward in tropical regions; and after doubling the Cape of Good Hope, where it runs nearly at the rate of two miles an hour, inclines considerably to the northward, along the western coast of Africa, then crosses the Atlantic, and, having accumulated in the Gulf of Mexico, passes out at the Straits of Bahama, with a velocity of more than four miles an hour, which is not reduced to two miles until the stream has proceeded to the distance of

* The heights of these tides are given on the authority of Captain Hewett, R.N.

† On the authority of Captain Beaufort, R.N.

eighteen hundred miles in the direction of Newfoundland. Near that island it meets with a current setting southward from Baffin's Bay, on the coast of Greenland, where it divides into several branches, one of which continues to hold a northerly direction, while another flows eastward, so that fruits, plants, and wood, the produce of America and the West Indies, are drifted to the shores of Ireland, the Hebrides, and even to Spitzbergen.

Velocity of Currents.—On our eastern coast the strongest currents seldom exceed four miles and a half an hour. The current which runs through the Race of Alderney, between the island of that name and the main land, has a velocity of above eight English miles an hour. Captain Hewett found that in the Pentland Firth the stream, in ordinary spring tides, runs ten miles and a half an hour, and about thirteen miles during violent storms. The greatest velocity of the current through the "Shoots," or New Passage, in the Bristol Channel, is fourteen miles an hour; and Captain King observed, in his recent survey of the Straits of Magellan, that the tide ran at the same rate through the "First Narrows."

Causes of Currents.—That movements of no inconsiderable magnitude should be impressed on an expansive ocean, by winds blowing for many months in one direction, may easily be conceived, when we observe the effects produced in our own seas by the temporary action of the same cause. It is well known that a strong south-west or north-west wind invariably raises the tides to an unusual height along the east coast of England and in the Channel; and that a north-west wind of any continuance causes the Baltic to rise two feet and upwards above its ordinary level. Smeaton

ascertained by experiment that, in a canal four miles in length, the water was kept up four inches higher at one end than at the other, merely by the action of the wind along the canal; and Rennell informs us that a large piece of water, ten miles broad, and generally only three feet deep, has, by a strong wind, had its waters driven to one side, and sustained so as to become six feet deep, while the windward side was laid dry.*

As water, therefore, he observes, when pent up so that it cannot escape, acquires a higher level, so, in a place *where it can escape*, the same operation produces a current; and this current will extend to a greater or less distance, according to the force by which it is produced.

Currents flowing alternately in opposite directions are also occasioned by the rise and fall of the tides. The effect of this cause is, as before observed, most striking in estuaries and channels between islands.

A third cause of oceanic currents is evaporation by solar heat, of which the great current setting through the Straits of Gibraltar into the Mediterranean is a remarkable example, and will be fully considered in the next chapter. It has been suggested by Captain Owen †, that the perennial current which sets into the Atlantic Ocean round the Cape of Good Hope, as well as that which he describes as flowing northwards, from the shores of Cape Horn, are in like manner due to the evaporation of the Atlantic between the tropics. This suggestion deserves attention, although it has been fairly objected that the strong current setting out of the Gulf of Mexico seems in-

* Rennell on the Channel-current.

† Nar. of Voyages on Coast of Africa,

consistent with such a theory. Nevertheless it must often happen that large quantities of water raised from one tract of the ocean by solar heat, and carried to some other where the vapour is condensed and falls in the shape of rain, will, in flowing back again to restore equilibrium, cause sensible currents. The influx of a great river into the sea, and the movement to which it gives rise is nothing more than the result of similar evaporation.

But there is another way in which heat and cold must occasion currents in the ocean. It is now ascertained that there is no maximum of density in salt water,—no point, as in fresh water, at which an increase of cold causes the fluid to begin again to expand. Whenever, therefore, the temperature of the surface is lowered, condensation takes place, and the superficial water, having its specific gravity thus increased, falls to the bottom, upon which lighter water rises immediately and occupies its place. When this circulation of ascending and descending currents has gone on for a certain time in high latitudes, the inferior parts of the sea are made to consist of colder or heavier fluid than the corresponding depths of the ocean between the tropics. If there be a free communication; if no chain of submarine mountains divide the polar from the equatorial basins, a horizontal movement will arise by the flowing of colder water from the poles to the equator, and there will be a reflux of warmer superficial water from the equator to the poles. A well known experiment has been adduced to elucidate this mode of action in explanation of the “trade winds.”* If a long trough, divided in

* See Capt. B. Hall’s clear Explanation of the Theory of the Trade Winds, Fragments of Voyages, second series, vol. i. and his letter in the Appendix to Daniell’s Meteorology.

the middle by a sluice or partition, have one end filled with water and the other with quicksilver, both fluids will remain quiet so long as they are divided; but when the sluice is drawn up, the heavier fluid will rush along the bottom of the trough, while the lighter, being displaced, will rise and spread itself at the top. Hence it appears, that the expansion and contraction of sea-water by heat and cold have a tendency to set under-currents in motion from the poles to the equator, and to cause counter-currents at the surface, which are impelled in a direction contrary to that of the prevailing trade winds. The circumstances being so complicated, and often of so conflicting a nature, we cannot expect to trace separately the movements due to each cause, but must be prepared for many anomalies, especially as the configuration of the bed of the ocean must often modify and interfere with the course of the inferior currents as much as the position and form of continents and islands are found to alter the direction of those on the surface.

Each of the four causes above mentioned, the wind, the tides, evaporation, and expansion of water by heat, may be conceived to operate independently of the others, and although the influence of all the rest were annihilated. But there is another cause, the rotation of the earth on its axis, which can only come into play when the waters have already been set in motion by some one or all of the forces above described, and only when the direction of the current so raised happens to be from south to north, or from north to south. *

* In an interesting essay in the United Service Journal (Dec. 1833), an attempt is made to introduce the earth's rotation as a primary cause of currents. But the author appears to misconceive the mode in which alone this rotation could produce any effect, and reasons as if it would in all latitudes cause currents

The principle on which this cause operates is probably familiar to the reader, as it has long been recognized in the case of the trade winds. Without enlarging, therefore, on the theory, it will be sufficient to offer an example of the mode of action alluded to. When a current flows from the Cape of Good Hope towards the Gulf of Guinea, it consists of a mass of water, which, on doubling the Cape, in lat. 35° , has a rotatory velocity of about 800 miles an hour; but when it reaches the line, it arrives at a parallel where the surface of the earth is whirled round at the rate of 1000 miles an hour, or about 200 miles faster.* If this great mass of water was transferred suddenly from the higher to the lower latitude, the deficiency of its rotatory motion, relatively to the land and water with which it would come into juxtaposition would be such as to cause an apparent motion of the most rapid kind (of no less than 200 miles an hour) from east to west.

The eastern coast of America might be carried round so as to strike against such a body of water with tremendous violence, so that a large part of the continent might be submerged. This disturbance does not occur, because the water of the stream, as it advances gradually into new zones of the sea which are moving more rapidly, acquires by friction an accelerated velocity. Yet as this motion is not imparted instantaneously

from east to west. He also seems never to have heard of Mr. Lloyd's levellings across the Isthmus of Panama, by which the waters of the Gulf of Mexico are proved (if there be any difference) to be lower than the mean level of the Pacific, and he also assumes that the quantity of rain is greatly in excess in *high* instead of *low* latitudes.

* See a table in Capt. Hall's work before cited.

neously, the fluid is unable to keep up with the full speed of the new surface over which it is successively brought. Hence, to borrow the language of Herschel, when he speaks of the trade winds, "it lags or hangs back, in a direction opposite to the earth's rotation, that is, from east to west*," and thus a current which would have run simply towards the north but for the rotation, may acquire a relative direction towards the west, or become a south-easterly current.

We may next consider a case where the circumstances are the converse of the above. The Gulf stream flowing from about lat. 20° , is impressed with a velocity of rotation of about 940 miles an hour, and runs to the lat. 50° , where the earth revolves only at the rate of 640 miles, or 300 miles slower. In this case a relative motion of an opposite kind may result; and the current may retain an excess of rotatory velocity, tending continually to deflect it eastward.

Thus it will be seen that currents depend like the tides on no temporary or accidental circumstances, but on the laws which preside over the motions of the heavenly bodies. But although the sum of their influence in altering the surface of the earth may be very constant throughout successive epochs, yet the points where these operations are displayed in fullest energy shift perpetually. The height to which the tides rise, and the violence and velocity of currents, depend in a great measure on the actual configuration of the land, the contour of a long line of continental or insular coast, the depth and breadth of channels, the peculiar form of the bottom of seas—in a word, on a combination of circumstances which are made to vary continually

* Treatise on Astronomy, chap. 3.

by many igneous and aqueous causes, and among the rest, by the tides and currents themselves. Although these agents, therefore, of decay and reproduction, are local in reference to periods of short duration, such as those which history embraces, they are nevertheless universal, if we extend our views to a sufficient lapse of ages.

In describing the destroying effects of tides and currents, it will be necessary to enter into some detail, because we have not the advantage here, as in the case of many river-deltas, of viewing the aggregate mass which has resulted from the continual transportation of matter, for many centuries, at certain points. We must infer the great amount of accumulation as a corollary from the proofs adduced of the removing force; and this it will not be difficult to show is, on the whole, far greater than that of running water on the land.

Action of the Sea on the British Coasts.—If we follow the eastern and southern shores of the British islands, from our Ultima Thule in Shetland to the Land's End in Cornwall, we shall find evidence of a series of changes since the historical era, very illustrative of the kind and degree of force exerted by the agents now under consideration. In this survey we shall have an opportunity of tracing the power of the sea on islands, promontories, bays, and estuaries; on bold, lofty cliffs, as well as on low shores; and on every description of rock and soil, from granite to blown sand.

Shetland Islands.—The northernmost group of the British islands, the Shetland, are composed of a great variety of hypogene and trap rocks, including granite, gneiss, mica-slate, serpentine, greenstone, and many others, with some secondary rocks, chiefly sandstone and conglomerate. These isles are exposed continually

to the uncontrolled violence of the Atlantic, for no land intervenes between their western shores and America. The prevalence, therefore, of strong westerly gales causes the waves to be sometimes driven with irresistible force upon the coast, while there is also a current setting from the north. The spray of the sea aids the decomposition of the rocks, and prepares them to be breached by the mechanical force of the waves. Steep cliffs are hollowed out into deep caves and lofty arches ; and almost every promontory ends in a cluster of rocks, imitating the forms of columns, pinnacles, and obelisks.

Drifting of large Masses of Rock. — Modern observations show that the reduction of continuous tracts to such insular masses is a process in which Nature is still actively engaged. “ The Isle of Stenness,” says Dr. Hibbert, “ presents a scene of unequalled desolation. In stormy winters, huge blocks of stones are overturned or are removed from their native beds, and hurried up a slight acclivity to a distance almost incredible. In the winter of 1802, a tabular-shaped mass, eight feet two inches by seven feet, and five feet one inch thick, was dislodged from its bed, and removed to a distance of from eighty to ninety feet. I measured the recent bed from which a block had been carried away the preceding winter (A.D. 1818), and found it to be seventeen feet and a half by seven feet, and the depth two feet eight inches. The removed mass had been borne to a distance of thirty feet, when it was shivered into thirteen or more lesser fragments, some of which were carried still farther, from 30 to 120 feet. A block, nine feet two inches by six feet and a half, and four feet thick, was hurried up the acclivity to a distance of 150 feet.” *

* Descrip. of Shetland Islands, p. 527. Edin. 1822.

At Northmavine, also, angular blocks of stone have been removed in a similar manner to considerable distances by the waves of the sea, some of which are represented in the annexed figure, No. 8. *

No. 8.

Stony fragments drifted by the sea. Northmavine, Shetland.

Effects of Lightning. — In addition to numerous examples of masses detached and driven by the tides and currents from their place, some remarkable effects of lightning are recorded in these isles. At Funzie, in Fetlar, about the middle of the last century, a rock of mica-schist, 105 feet long, ten feet broad, and in some places four feet thick, was in an instant torn by a flash of lightning from its bed, and broken into three large, and several lesser, fragments. One of these, twenty-six feet long, ten feet broad, and four feet thick, was simply turned over. The second, which was twenty-eight feet long, seventeen broad, and five

* For this and the three following representations of rocks in the Shetland Isles, I am indebted to Dr. Hibbert's work before cited, which is rich in antiquarian and geological research.

feet in thickness, was hurled across a high point to the distance of fifty yards. Another broken mass, about forty feet long, was thrown still farther, but in the same direction, quite into the sea. There were also many lesser fragments scattered up and down.*

When we thus see electricity co-operating with the violent movements of the ocean in heaping up piles of shattered rocks on dry land, and beneath the waters, we cannot but admit that a region which shall be the theatre, for myriads of ages, of the action of such disturbing causes, will present, at some future period, a scene of havoc and ruin that may compare with any now found by the geologist on the surface of our continents, raised as they all have been in former ages from the bosom of the deep. We have scarcely begun, as yet, to study the effects of a single class of the mighty instruments of change and disorder now operating on our globe ; and yet geologists have presumed to resort to a nascent order of things, or to revolutions in the economy of nature, to explain every obscure phenomenon !

In some of the Shetland Isles, as on the west of Meikle Roe, dikes, or veins of soft granite, have mouldered away ; while the matrix in which they were inclosed, being of the same substance, but of a firmer texture, has remained unaltered. Thus, long narrow ravines, sometimes twenty feet wide, are laid open, and often give access to the waves. After describing some huge cavernous apertures into which the sea flows for 250 feet in Roeness, Dr. Hibbert enumerates other ravages of the ocean. “ A mass of rock, the average dimensions of which may perhaps be rated at twelve

* Dr. Hibbert, from MSS. of Rev. George Low, of Fetlar.

or thirteen feet square, and four and a half or five in thickness, was first moved from its bed, about fifty years ago, to a distance of thirty feet, and has since been twice turned over."

Passage forced by the sea through porphyritic rocks.—
"But the most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears to have been left as a sort of rampart against the inroads of the ocean;—the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery—the waves having, in their repeated assaults, forced themselves an entrance. This breach, named the Grind of the Navir (No. 9.), is widened every winter by the overwhelming surge that, finding a passage through it, separates large stones from its sides, and forces them

No. 9

Grind of the Navir — Passage forced by the sea through rocks of hard porphyry.

to a distance of no less than 180 feet. In two or three spots, the fragments which have been detached are brought together in immense heaps, that appear as an accumulation of cubical masses, the product of some quarry." *

It is evident, from this example, that although the greater indestructibility of some rocks may enable them to withstand, for a longer time, the action of the elements, yet they cannot permanently resist. There are localities in Shetland, in which rocks of almost every variety of mineral composition are suffering disintegration: thus the sea makes great inroads on the clay slate of Fitfel Head, on the serpentine of the Vord Hill in Fetlar, and on the mica-schist of the Bay of Triesta, on the east coast of the same isle, which decomposes into angular blocks. The quartz rock on the east of Walls, and the gneiss and mica-schist of Garthness, suffer the same fate.

Destruction of Islands. — Such devastation cannot be incessantly committed for thousands of years without dividing islands, until they become at last mere clusters of rocks, the last shreds of masses once continuous. To this state many appear to have been reduced, and innumerable fantastic forms are assumed by rocks adjoining these isles, to which the name of Drongs is applied, as it is to those of similar shape in Feroe.

The granitic rocks (No. 10.) between Papa Stour and Hillswick Ness afford an example. A still more singular cluster of rocks is seen to the south of Hillswick Ness (No. 11.), which presents a variety of forms as viewed from different points, and has often been likened to a small fleet of vessels with spread

* Hibbert, p. 528.

No. 10.

*Granitic rocks named the Drongs, between Papa Stour and
Hillswick Ness.*

sails.* We may imagine that in the course of time
Hillswick Ness itself may present a similar wreck,

No. 11.

Granitic rocks to the south of Hillswick Ness, Shetland.

* Hibbert, p. 519.

from the unequal decomposition of the rocks whereof it is composed, consisting of gneiss and mica-schist, traversed in all directions by veins of felspar porphyry.

Midway between the groups of Shetland and Orkney is Fair Island, said to be composed of sandstone with high perpendicular cliffs. The current runs with such velocity, that during a calm, and when there is no swell, the rocks on its shores are white with the foam of the sea driven against them. The Orkneys, if carefully examined, would probably illustrate our present topic as much as the Shetland Islands. The north-east promontory of Sanda, one of these isles, has been cut off in modern times by the sea, so that it became what is now called Start Island, where a lighthouse was erected in 1807, since which time the new strait has grown broader.

East coast of Scotland.—To pass over to the main land of Scotland, we find that, in Inverness-shire, there have been inroads of the sea at Fort George, and others in Murrayshire, which have swept away the old town of Findhorn. On the coast of Kincardineshire, an illustration was afforded, at the close of the last century, of the effect of promontories in protecting a line of low-shore. The village of Mathers, two miles south of Johnshaven, was built on an ancient shingle beach, protected by a projecting ledge of limestone rock. This was quarried for lime to such an extent, that the sea broke through, and in 1795 carried away the whole village in one night, and penetrated 150 yards inland, where it has maintained its ground ever since, the new village having been built farther inland on the new shore. In the Bay of Montrose, we find the North Esk and the South Esk rivers pouring annually into the sea large quantities of sand and

pebbles, yet they have formed no deltas; for the tides scour out the channels, and the current, setting across their mouths, sweeps away all the materials. Considerable beds of shingle, brought down by the North Esk, are seen along the beach.

Proceeding southwards, we find that at Arbroath, in Forfarshire, which stands on a rock of red sandstone, gardens and houses have been carried away within the last thirty years by encroachments of the sea. It has become necessary to remove the lighthouses at the mouth of the estuary of the Tay, in the same county, at Button Ness, which were built on a tract of blown sand, the sea having encroached for three quarters of a mile.

Force of Currents in Estuaries.—The power which currents can exert in estuaries to considerable depths, was remarkably exhibited during the building of the Bell Rock Lighthouse, at the mouth of the Tay. The Bell Rock is a sunken reef, consisting of red sandstone, being from twelve to sixteen feet under the surface at high water, and about twelve miles from the mainland. At the distance of 100 yards, there is a depth, in all directions, of two or three fathoms at low water. The perpendicular rise and fall of the spring tides is fifteen feet, and at neap tides eight feet; their velocity varying from one to three miles per hour. In 1807, during the erection of the lighthouse, six large blocks of granite, which had been landed on the reef, were removed by the force of the sea, and thrown over a rising ledge to the distance of twelve or fifteen paces; and an anchor, weighing about 22 cwt., was thrown up upon the rock.* Mr. Stevenson informs us, moreover, that drift stones, measuring up-

Account of the Erection of the Bell Rock Lighthouse, p. 163.

wards of thirty cubic feet, or more than two tons weight, have, during storms, been often thrown upon the rock from the deep water.*

Submarine forests.—Among the proofs that the sea has encroached both on the estuaries of the Tay and Forth, may be mentioned the submarine forests which have been traced for several miles by Dr. Fleming, along the margins of those estuaries on the north and south shores of the county of Fife.† The alluvial tracts, however, on which such forests grow, generally occupy spaces which may be said to be in dispute between the river and the sea, and to be alternately lost and won. *Estuaries* (a term which we confine to inlets entered both by rivers and tides of the sea) have a tendency to become silted up in parts; but the same tracts, after remaining dry, perhaps, for thousands of years, are again liable to be overflowed, for they are always low, and, if inhabited, must generally be secured by artificial embankments. Meanwhile the sea devours, as it advances, the high as well as the low parts of the coast, breaking down, one after another, the rocky bulwarks which protect the mouths of estuaries. The changes of territory, therefore, within the general line of coast are all of a subordinate nature, in no way tending to arrest the march of the great ocean, nor to avert the destiny eventually awaiting the whole region; they are like the petty wars and conquests of the independent states and republics of Greece, while the power of Macedon was steadily pressing on, and preparing to swallow up the whole.

* Ed. Phil. Journ., vol. iii. p. 54. 1820.

† Quarterly Journal of Science, &c., No. xii. New Series, March, 1830.

On the coast of Fife, at St. Andrew's, a tract of land which intervened between the castle of Cardinal Beaton and the sea has been entirely swept away, as were the last remains of the Priory of Crail, in the same county, in 1803. On both sides of the Frith of Forth, land has been consumed; at North Berwick in particular, and at Newhaven, where an arsenal and dock, built in the reign of James IV., in the fifteenth century, has been overflowed.

East coast of England. — If we now proceed to the English coast, we find records of numerous lands having been destroyed in Northumberland, as those near Bamborough and Holy Island, and at Tynemouth castle, which now overhangs the sea, although formerly separated from it by a strip of land. At Hartlepool, and several other parts of the coast of Durham composed of magnesian limestone, the sea has made considerable inroads.

Coast of Yorkshire. — Almost the whole coast of Yorkshire, from the mouth of the Tees to that of the Humber, is in a state of gradual dilapidation. That part of the cliffs which consists of lias, the oolite series, and chalk, decays slowly. They present abrupt and naked precipices, often 300 feet in height; and it is only at a few points that the grassy covering of the sloping talus marks a temporary relaxation of the erosive action of the sea. The chalk cliffs are washed into caves in the projecting headland of Flamborough, where they are decomposed by the salt vapours, and slowly crumble away. But the waste is most rapid between that promontory and Spurn Point, or the coast of Holderness, as it is called, a tract consisting of beds of clay, gravel, sand, and chalk rubble. The irregular intermixture of the argillaceous

beds causes many springs to be thrown out, and this facilitates the undermining process, the waves beating against them, and a strong current setting chiefly from the north. The wasteful action is very conspicuous at Dimlington Height, the loftiest point in Holderness, where the beacon stands on a cliff 146 feet above high water, the whole being composed of clay, with pebbles scattered through it.*

In the old maps of Yorkshire, we find spots, now sand-banks in the sea, marked as the ancient sites of the towns and villages of Auburn, Hartburn, and Hyde. "Of Hyde," says Pennant, "only the tradition is left; and near the village of Hornsea, a street called Hornsea Beck has long since been swallowed.†" Owthorne and its church have also been in great part destroyed, and the village of Kilnsea; but these places are now removed farther inland. The rate of encroachment at Owthorne, at present, is about *four yards a year*.‡ Not unreasonable fears are entertained that at some future time the Spurn Point will become an island, and that the ocean, entering into the estuary of the Humber, will cause great devastation. § Pennant, after speaking of the silting up of some ancient ports in that estuary, observes, "But, in return, the sea has made most ample reprisals; the site, and even the very names of several places, once towns of note upon the Humber, are now only recorded in history; and Ravensper was at one time a rival to Hull (Madox, Ant. Exch. i., 422.), and a port so very considerable in

* Phillips's Geology of Yorkshire, p. 61.

† Arctic Zoology, vol. i. p. 10. Introduction.

‡ For this information I am indebted to Mr. Phillips, of York.

§ Phillips's Geology of Yorkshire, p. 60.

1332, that Edward Baliol and the confederated English Barons sailed from hence to invade Scotland; and Henry IV., in 1399, made choice of this port to land at, to effect the deposal of Richard II., yet the whole of this has long since been devoured by the merciless ocean: extensive sands, dry at low water, are to be seen in their stead.”*

Pennant describes Spurn Head as a promontory in the form of a sickle, and says the land, for some miles to the north, was “perpetually preyed on by the fury of the German Sea, which devours whole acres at a time, and exposes on the shores considerable quantities of beautiful amber.”†

According to Bergmann, a strip of land, with several villages, was carried away near the mouth of the Humber in 1475.

Lincolnshire.—The maritime district of Lincolnshire consists chiefly of lands that lie below the level of the sea, being protected by embankments. Great parts of this fenny tract were, at some unknown period, a woody country, but were afterwards inundated, and are now again recovered from the sea. Some of the fens were embanked and drained by the Romans; but after their departure the sea returned, and large tracts were covered with beds of silt containing marine shells, now again converted into productive lands. Many dreadful catastrophes are recorded by incursions of the sea, whereby several parishes have been at different times overwhelmed.

Norfolk.—We come next to the cliffs of Norfolk and Suffolk, where the decay is in general incessant and rapid. At Hunstanton, on the north, the under-

* Arct. Zool., vol. i. p. 13. Introduction.

† Ibid.

mining of the lower arenaceous beds at the foot of the cliff causes masses of red and white chalk to be precipitated from above. Between Hunstanton and Weybourne, low hills, or dunes, of blown sand, are formed along the shore, from fifty to sixty feet high. They are composed of dry sand, bound in a compact mass by the long creeping roots of the plant called Marram (*Arundo arenaria*). Such is the present set of the tides, that the harbours of Clay, Wells, and other places, are securely defended by these barriers; affording a clear proof that it is not the strength of the material at particular points that determines whether the sea shall be progressive or stationary, but the general contour of the coast.

The waves constantly undermine the low chalk cliffs, covered with sand and clay, between Weybourne and Sherringham, a certain portion of them being annually removed. At the latter town I ascertained, in 1829, some facts which throw light on the rate at which the sea gains upon the land. It was computed, when the present inn was built, in 1805, that it would require seventy years for the sea to reach the spot; the mean loss of land being calculated, from previous observations, to be somewhat less than one yard annually. The distance between the house and the sea was fifty yards; but no allowance was made for the slope of the ground being *from* the sea, in consequence of which, the waste was naturally accelerated every year, as the cliff grew lower, there being at each succeeding period less matter to remove when portions of equal area fell down. Between the years 1824 and 1829, no less than seventeen yards were swept away, and only a small garden was then left between the building and the sea. There is now a depth of twenty

feet (sufficient to float a frigate) at one point in the harbour of that port, where, only forty-eight years ago, there stood a cliff fifty feet high, with houses upon it! If once in half a century an equal amount of change were produced suddenly by the momentary shock of an earthquake, history would be filled with records of such wonderful revolutions of the earth's surface, but, if the conversion of high land into deep sea be gradual, it excites only local attention. The flag-staff of the Preventive Service station, on the south side of this harbour, has, within the last fifteen years, been thrice removed inland, in consequence of the advance of the sea.

Farther to the south we find cliffs, composed, like those of Holderness before mentioned, of alternating strata of blue clay, gravel, loam, and fine sand. Although they sometimes exceed 200 feet in height, the havoc made on the coast is most formidable. The whole site of ancient Cromer now forms part of the German Ocean, the inhabitants having gradually retreated inland to their present situation, from whence the sea still threatens to dislodge them. In the winter of 1825, a fallen mass was precipitated from near the lighthouse, which covered twelve acres, extending far into the sea, the cliffs being 250 feet in height.* The undermining by springs has sometimes caused large portions of the upper part of the cliffs, with houses still standing upon them, to give way, so that it is impossible, by erecting breakwaters at the base of the cliffs, permanently to ward off the danger.

On the same coast, the ancient villages of Shipden, Wimpwell, and Eccles, have disappeared; several

* Taylor's *Geology of East Norfolk*, p. 32.

manors and large portions of neighbouring parishes having, piece after piece, been swallowed up; nor has there been any intermission, from time immemorial, in the ravages of the sea along a line of coast twenty miles in length, in which these places stood.* Hills of blown sand, between Eccles and Winterton, have barred up and excluded the tide for many hundred years from the mouths of several small estuaries; but there are records of nine breaches from 20 to 120 yards wide, having been made through these, whereby immense damage was done to the low grounds in the interior. A few miles south of Happisburgh, also, are hills of blown sand, which extend to Yarmouth; and these are supposed to protect the coast, but in fact their formation proves that a temporary respite of the incursions of the sea on this part is permitted by the present set of the tides and currents. Were it otherwise, the land, as we have seen, would give way, though made of solid rock.

Silting up of Estuaries.—At Yarmouth, the sea has not advanced upon the sands in the slightest degree since the reign of Elizabeth. In the time of the Saxons, a great estuary extended as far as Norwich, which city is represented, even in the thirteenth and fourteenth centuries, as “situated on the banks of an arm of the sea.” The sands whereon Yarmouth is built first became firm and habitable ground about the year 1008, from which time a line of dunes has gradually increased in height and breadth, stretching across the whole entrance of the ancient estuary, and obstructing the ingress of the tides so completely, that they are only admitted by the narrow passage which the river

* Taylor's Geology of East Norfolk, p. 32.

keeps open, and which has gradually shifted several miles to the south. The ordinary tides at the river's mouth only rise, at present, to the height of three or four feet, the spring tides to about eight or nine.

By the exclusion of the sea, thousands of acres in the interior have become cultivated lands; and, exclusive of smaller pools, upwards of sixty fresh-water lakes have been formed, varying in depth from fifteen to thirty feet, and in extent from one acre to twelve hundred*. The Yare, and other rivers, frequently communicate with these sheets of water; and thus they are liable to be filled up gradually with lacustrine and fluviatile deposits, and to be converted into land covered with forests. When the sea at length returns (for as the whole coast gives way, this must inevitably happen sooner or later), these tracts will be again submerged, and submarine forests may then be found, as along the margins of many estuaries.†

Yarmouth does not project beyond the general line of coast which has been rounded off by the predominating current from the north-west. It must not be imagined, therefore, that the acquisition of new land fit for cultivation in Norfolk and Suffolk indicates any permanent growth of the eastern limits of our island, to compensate its reiterated losses. No *delta* can form on such a shore.

That great banks should be thrown across the estuary of the Yare, or any other estuary on our eastern coast, where there is not a large body of river-water to maintain an open channel, is perfectly intelligible, when

* Taylor's Geology of East Norfolk, p. 10.

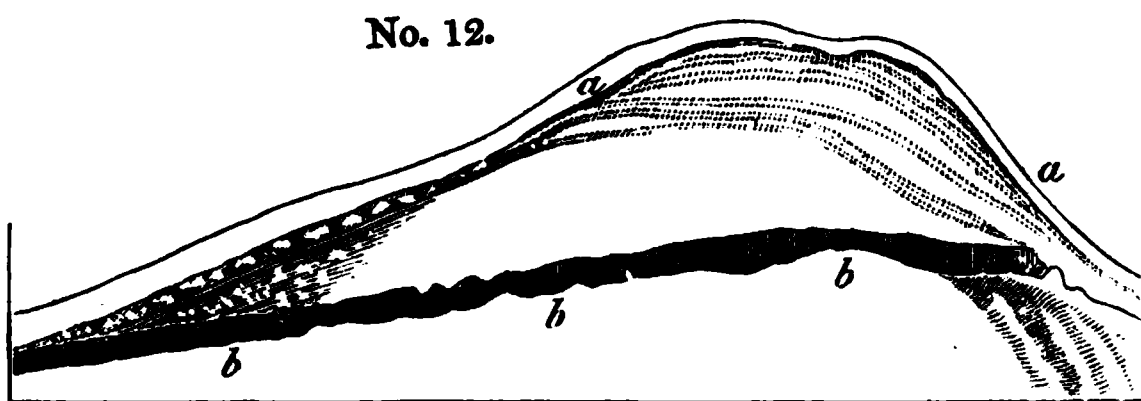
† For remarks on the origin of Submarine Forests, see Book III. chap. 16.

we bear in mind that the marine current, sweeping along our coast is charged with the materials of wasting cliffs and ready to form a bar anywhere, the instant its course is interrupted or checked by any opposing stream. The mouth of the Yare has been, within the last five centuries diverted about four miles to the south ; so it is evident that at some remote period the river Alde, entered the sea at Aldborough, until its ancient outlet was barred up and at length transferred to a point no less than ten miles distant to the south-west. In this case ridges of sand and shingle like those of Lowestoff Ness, which will be described by-and-by, have been thrown up between the river and the sea.

It may be asked why our rivers on the east coast are always deflected southwards, although the tidal current flows alternately from the south and north ? The cause is to be found in the superior force of what is commonly called "the flood tide from the north," a tidal wave derived from the Atlantic, a small part of which passes eastward up the English Channel, and through the Straits of Dover and then northwards, while the principal body of water, moving much more rapidly in a more open sea, first passes the Orkneys, and then turning flows down between Norway and Scotland, and sweeps with great velocity along our eastern coast. It is well known that the highest tides on this coast are occasioned by a powerful north-west wind which raises the eastern part of the Atlantic, and causes it to pour a greater volume of water into the German ocean. This circumstance of a violent *off-shore* wind being attended with a rise of the waters, instead of a general retreat of the sea, naturally excites the wonder of the inhabitants of our coast. In

many districts they look with confidence for a rich harvest of that valuable manure, the sea-weed, when the north-westerly gales prevail, and are rarely disappointed. The phenomenon is so well calculated to awaken curiosity, that I have heard the cause discussed by peasants and fishermen ; and more than once they have hazarded a theory of their own to account for it. The most ingenious idea which I heard suggested was this ; a vast body of surface water, say they, is repelled by the wind from the shore, which afterwards returns, in order to restore the level of the sea ; by this means a strong under-current is produced, which tears up the weed from the bed of the sea, and casts it ashore.

Coast of Suffolk.—The cliffs of Suffolk, to which we next proceed, are somewhat less elevated than those of Norfolk, but composed of similar accumulations of alternating clay, sand, and gravel. From Gorleston in Suffolk, to within a few miles north of Lowestoff, the cliffs are slowly undermined. Near the last-mentioned town, there is an inland cliff about sixty feet high, the talus being covered with turf and heath, between which



Map of Lowestoff Ness, Suffolk.

a, a. The dotted lines express a series of ridges of sand and shingle, forming the extremity of the triangular space called the Ness.

b, b, b. The dark line represents the inland cliff on which the town of Lowestoff stands, between which and the sea is the Ness.

and the sea is a low, flat tract of sand, called the Ness, nearly three miles long, and for the most part out of reach of the highest tides. The point of the Ness projects from the base of the original cliff to the distance of 660 yards. This accession of land, says Mr. Taylor, has been effected at distinct and distant intervals, by the influence of currents running between the land and a shoal about a mile off Lowestoff, called the Holm Sand. The lines of growth in the Ness are indicated by a series of concentric ridges or embankments inclosing limited areas, and several of these ridges have been formed within the observation of persons now living. A rampart of heavy materials is first thrown up to an unusual altitude by some extraordinary tide, attended with a violent gale. Subsequent tides extend the base of this high bank of shingle, and the interstices are then filled with sand blown from the beach. The *Arundo* and other marine plants by degrees obtain a footing, and creeping along the ridge, give solidity to the mass, and form in some cases a matted covering of turf. Meanwhile another mound is forming externally, which by the like process rises and gives protection to the first. If the sea forces its way through one of the external and incomplete mounds, the breach is soon repaired. After a while the marine plants within the areas inclosed by these embankments are succeeded by a better species of herbage, affording good pasturage, and the sands become sufficiently firm to support buildings.*

Destruction of Dunwich by the Sea.—The sea undermines the high cliffs near Córton, a few miles north of

* The formation of the Ness is well described by Mr. R. C. Taylor, *Phil. Mag.* Oct. 1827. p. 297.

Lowestoff, as also two miles south of the same town, at Pakefield, a village which has been in part swept away during the present century. From thence to Dunwich the destruction is constant. At the distance of 250 yards from the wasting cliff at Pakefield, where we must suppose land to have existed at no remote period, the sea is sixteen feet deep at low water, and in the roadstead beyond, twenty-four feet. Of the gradual destruction of Dunwich, once the most considerable seaport on this coast, we have many authentic records. Gardner, in his history of that borough, published in 1754, shows, by reference to documents beginning with Domesday Book, that the cliffs at Dunwich, Southwold, Eastern, and Pakefield, have been always subject to wear away. At Dunwich, in particular, two tracts of land which had been taxed in the eleventh century, in the time of King Edward the Confessor, are mentioned, in the Conqueror's survey, made but a few years afterwards, as having been devoured by the sea. The losses, at a subsequent period, of a monastery,—at another of several churches,—afterwards of the old port,—then of four hundred houses at once,—of the church of St. Leonard, the high road, town-hall, gaol, and many other buildings, are mentioned, with the dates when they perished. It is stated that, in the sixteenth century, not one quarter of the town was left standing; yet the inhabitants retreating inland, the name was preserved, as has been the case with many other ports, when their ancient site has been blotted out. There is, however, a church, of considerable antiquity, still standing, the last of twelve mentioned in some records. In 1740, the laying open of the churchyard of St. Nicholas and St. Francis, in the sea-cliff, is well described by Gardner, with

the coffins and skeletons exposed to view — some lying on the beach, and rocked—

“ In cradle of the rude imperious surge.”

Of these cemeteries no remains can now be seen. Ray also says, “ that ancient writings make mention of a wood a mile and a half to the east of Dunwich, the site of which must at present be so far within the sea.”* This city, once so flourishing and populous, is now a small village, with about twenty houses, and one hundred inhabitants.

There is an old tradition, “ that the tailors sat in their shops at Dunwich, and saw the ships in Yarmouth Bay:” but when we consider how far the coast at Lowestoff Ness projects between these places, we cannot give credit to the tale, which, nevertheless, proves how much the inroads of the sea in times of old had prompted men of lively imagination to indulge their taste for the marvellous.

Gardner’s description of the cemeteries laid open by the waves reminds us of the scene which has been so well depicted by Bewick†, and of which numerous points on our coast might have suggested the idea. On the verge of a cliff, which the sea has undermined, are represented the unshaken tower and western end of an abbey. The eastern aisle is gone, and the pillars of the cloister are soon to follow. The waves have almost isolated the promontory, and invaded the cemetery, where they have made sport with the mortal relics, and thrown up a skull upon the beach. In the foreground is seen a broken tombstone, erected, as its

* Consequences of the Deluge, Phys. Theol. Discourses.

† History of British Birds, vol. ii. p. 220. Ed. 1821.

legend tells “to *perpetuate* the memory” of one whose name is obliterated, as is that of the county for which he was “Custos Rotulorum.” A cormorant is perched on the monument, defiling it, as if to remind some moraliser, like Hamlet, of “the base uses” to which things sacred may be turned. Had this excellent artist desired to satirise certain popular theories of geology, he might have inscribed the stone to the memory of some philosopher who taught “the permanency of existing continents” — “the era of repose” — “the impotence of modern causes.”

South of Dunwich are two cliffs, called Great and Little Cat Cliff. That which bears the name of Great has become the smallest of the two, and is only fifteen feet high, the more elevated portion of the hill having been carried away; on the other hand, the Lesser Cat Cliff has gained in importance, for the sea has here been cutting deeper into a hill which slopes towards it. But at no distant period, the ancient names will again become appropriate, for at Great Cliff the base of another hill will soon be reached, and at Little Cat Cliff the sea will, at about the same time, arrive at a valley.

The incursions of the sea at Aldborough were formerly very destructive, and this borough is known to have been once situated a quarter of a mile east of the present shore. The inhabitants continued to build farther inland, till they arrived at the extremity of their property, and then the town decayed greatly; but two sand-banks, thrown up at a short distance, now afford a temporary safeguard to the coast. Between these banks and the present shore, where the current now flows, the sea is twenty-four feet deep on the spot where the town formerly stood.

Continuing our survey of the Suffolk coast to the

southward, we find that the cliffs of Bawdsey and Felixtow are foundering slowly, and that the point on which Landguard Fort is built suffers gradual decay. It appears that, within the memory of persons now living, the Orwell river continued its course in a more direct line to the sea, and entered to the north instead of the south of the low bank on which the fort last mentioned is built.

Essex. — Harwich, in Essex, stands on an isthmus, which will probably become an island in little more than half a century ; for the sea will then have made a breach near Lower Dover Court, should it continue to advance as rapidly as it has done during the last fifty years. Within ten years, there was a considerable space between the battery at Harwich, built twenty-three years ago, and the sea ; part of the fortification has already been swept away, and the rest overhangs the water. Since the year 1807, a field called the Vicar's Field, which belonged to the living of Harwich, has been totally annihilated. *

At Walton Naze, in the same county, the cliffs, composed of London clay, capped by the shelly sands of the crag, reach the height of about 100 feet, and are annually undermined by the waves. The old churchyard of Walton has been washed away, and the cliffs to the south are continually disappearing.

Isle of Sheppey. — On the coast bounding the estuary of the Thames, there are numerous examples both of the gain and loss of land. The Isle of Sheppey, which is now about six miles long by four in breadth, is composed of London clay. The cliffs on the north, which

* On authority of Dr. Mitchell, F.G.S.

are from sixty to eighty feet high, decay rapidly, fifty acres having been lost within the last twenty years. The church at Minster, now near the coast, is said to have been in the middle of the island fifty years ago * ; and it has been conjectured that, at the present rate of destruction, the whole isle will be annihilated in about half a century. On the coast of the mainland to the east of Sheppey stands the church of Reculver, upon a cliff composed of clay and sand, about twenty feet high. Reculver (Regulvium), was an important military station in the time of the Romans, and appears, from Leland's account, to have been, so late as Henry VIII.'s reign, nearly one mile distant from the sea. In the "Gentleman's Magazine," there is a view of it about the middle of the last century, which still represents a considerable space as intervening between the north wall of the churchyard and the cliff.† Some time before the year 1780, the waves had reached the site of the ancient Roman camp, or fortification, the walls of which had continued for several years after they were undermined to overhang the sea, being firmly cemented into one mass. They were eighty yards nearer the sea than the church, and they are spoken of in the "Topographica Britannica" in the year 1780, as having recently fallen down.‡ In 1804, part of the churchyard with some adjoining houses was washed away, and the ancient church, with its two lofty spires, a well known land mark, was dismantled and abandoned as a place of worship. It is still standing (1833), but would probably have been

* For this information I am indebted to W. Gunnel, Esq.

† Rev. W. Conybeare's Outlines of Geology, &c. p. 82.

‡ Dr. Mitchell, Proceedings of Geol. Soc. vol. ii. No. 1.

annihilated ere this, had not the force of the waves been checked by an artificial causeway of stones and large wooden piles driven into the sands to break the force of the waves. *

Isle of Thanet. — The Isle of Thanet was, in the time of the Romans, separated from the rest of Kent by a navigable channel through which the Roman fleets sailed on their way to and from London. Bede describes this small estuary as being, in the beginning of the eighth century, three furlongs in breadth ; and it is supposed that it began to grow shallow about the period of the Norman conquest. It was so far silted up in the year 1485, that an act was then obtained to build a bridge across it ; and it has since become marsh land with small streams running through it. Bedlam Farm, belonging to the hospital of that name, has lost eight acres in the last twenty years, the land being chalk from forty to fifty feet above the level of the sea. It has been computed, that the average waste of the cliff between the North Foreland and the Reculvers, a distance of about eleven miles, is not less than two feet per annum. The chalk cliffs on the south of Thanet, between Ramsgate and Pegwell Bay, have on an average lost three feet per annum for the ten last years (preceding 1830).

Goodwin Sands. — The Goodwin Sands lie opposite this part of the Kentish coast. They are about ten miles in length, and are in some parts three, and in others seven miles distant from the shore, and, for a certain space, are laid bare at low water. That they are a remnant of land, and not “ a mere accumulation of sea sand,” as Rennell imagined †, may be presumed

* Dr. Mitchell, Proceedings of Geol. Soc. vol. ii. No. I.

† Geog. of Herod. vol. ii. p. 326.

from the fact that, when the erection of a lighthouse on this shoal was in contemplation by the Trinity Board in the year 1817, it was found, by borings, that the bank consisted of fifteen feet of sand, resting on blue clay. An obscure tradition has come down to us, that the estates of Earl Goodwin, the father of Harold, who died in the year 1053, were situated here, and some have conjectured that they were overwhelmed by the flood mentioned in the Saxon chronicle, *sub anno* 1099. The last remains of an island, consisting, like Sheppey, of clay, may, perhaps, have been carried away about that time.

Coast of Kent.—In the county of Kent, there are other records of waste, as at Deal; and at Dover, where Shakspeare's cliff, composed entirely of chalk, has suffered greatly, and continually diminishes in height, the slope of the hill being towards the land. About the year 1810 there was an immense land-slip from this cliff, by which Dover was shaken as if by an earthquake, and a still greater one in 1772.*

Straits of Dover.—In proceeding from the northern parts of the German Ocean towards the Straits of Dover, the water becomes gradually more shallow, so that in the distance of about two hundred leagues we pass from a depth of 120, to that of 58, 38, 24, and 18 fathoms. In the same manner the English Channel deepens progressively from Dover to its entrance, formed by the Land's End of England, and the Isle of Ushant on the Coast of France; so that the strait between Dover and Calais may be said to part two seas. †

* Dodsley's Ann. Regist. 1772.

† Stevenson on the Bed of the German Ocean. — Ed. Phil. Journ., No. v. p. 45.

Whether England was formerly united with France has often been a favourite subject of speculation ; and in 1753 a society at Amiens proposed this as a subject of a prize essay, which was gained by the celebrated Desmarest, then a young man. He founded his principal arguments on the identity of composition of the cliffs on the opposite sides of the Channel, on a submarine chain extending from Boulogne to Folkestone, only fourteen feet under low water, and on the identity of the noxious animals in England and France, which could not have swum across the Straits, and would never have been introduced by man. He also attributed the rupture of the isthmus to the preponderating violence of the current from the north.* It will hardly be disputed that the ocean might have effected a breach through the land which, in all probability, once united our country to the Continent in the same manner as it now gradually forces a passage through rocks of the same mineral composition, and often many hundred feet high, upon our coast.

Although the time required for such an operation was probably very great, yet we cannot estimate it by reference to the present rate of waste on both sides of the Channel. For when, in the thirteenth century, the sea burst through the isthmus of Staveren, which formerly united Friesland with North Holland, it opened, in about one hundred years, a strait more than half as wide as that which divides England from France, after which the dimensions of the new channel remained almost stationary. The greatest depth of the straits between Dover and Calais is twenty-nine fathoms, which only exceeds by one fathom the

* Cuvier, *Eloge de Desmarest*.

greatest depth of the Mississippi at New Orleans. If the moving column of water in the great American river, which, as was before mentioned, does not flow rapidly, can maintain an open passage to that depth in its alluvial accumulations, still more might a channel of the same magnitude be excavated by the resistless force of the tides and currents of "the ocean stream,"

ποταμοιο μεγα σθενος Ωκεανοιο.

At Folkestone, the sea eats away the chalk and subjacent strata. About the year 1716 there was a remarkable sinking of a tract of land near the sea, so that houses became visible at points near the shore from whence they could not be seen previously. In the description of this subsidence in the Philosophical Transactions, it is said, "that the land consisted of a solid stony mass (chalk), resting on wet clay (gault), so that it slid forwards towards the sea, just as a ship is launched on tallowed planks." It is also stated that, within the memory of persons then living, the cliff there had been washed away to the extent of ten rods.*

Encroachments of the sea at Hythe are also on record; but between this point and Rye there has been a gain of land within the times of history; the rich level tract called Romney Marsh, or Dungeness, about ten miles in width and five in breadth, and formed of silt, having received great accession. It has been necessary, however, to protect it from the sea, from the earliest periods, by a wall. These additions of land are exactly opposite that part of the English Channel where the conflicting tide-waves from the

* Phil. Trans., 1716.

north and south meet; for, as that from the north is, for reasons already explained, the most powerful, they do not neutralise each other's force till they arrive at this distance from the straits of Dover. Rye, on the south of this tract, was once destroyed by the sea, but it is now two miles distant from it. The neighbouring town of Winchelsea was destroyed in the reign of Edward I., the mouth of the Rother stopped up, and the river diverted into another channel. In its old bed an ancient vessel, apparently a Dutch merchantman, was recently found. It was built entirely of oak, and much blackened.*

South Coast of England.—To pass over some points near Hastings, where the cliffs have wasted at several periods, we arrive at the promontory of Beachy Head. Here a mass of chalk, three hundred feet in length, and from seventy to eighty in breadth, fell, in the year 1813, with a tremendous crash; and similar slips have since been frequent.†

Sussex.—About a mile to the west of the town of Newhaven the remains of an ancient intrenchment are seen, on the brow of Castle Hill. This earth-work, supposed to be Roman, was evidently once of considerable extent and of an oval form, but the greater part has been cut away. The cliffs, which are undermined here, are high; more than one hundred feet of chalk being covered by tertiary clay and sand, from sixty to seventy feet in thickness. In a few centuries the last vestiges of the plastic clay formation on the southern borders of the chalk of the South Downs on this coast will be annihilated, and

* Edin. Journ. of Sci., No. xix. p. 56.

† Webster, Geol. Trans., vol. ii. p. 192.

future geologists will learn, from historical documents, the ancient geographical boundaries of this group of strata in that direction. On the opposite side of the estuary of the Ouse, on the east of Newhaven harbour, a bed of shingle, composed of chalk flints, derived from the waste of the adjoining cliffs, had accumulated at Seaford for several centuries. In the great storm of November, 1824, this bank was entirely swept away, and the town of Seaford inundated. Another great beach of shingle is now forming from fresh materials.

The whole coast of Sussex has been incessantly encroached upon by the sea from time immemorial; and, although sudden inundations only, which overwhelmed fertile or inhabited tracts are noticed in history, the records attest an extraordinary amount of loss. During a period of no more than eighty years, there are notices of about *twenty* inroads, in which tracts of land of from twenty to *four hundred acres* in extent were overwhelmed at once; the value of the tithes being mentioned by Nicholas, in his *Taxatio Ecclesiastica*.* In the reign of Elizabeth, the town of Brighton was situated on that tract where the chain pier now extends into the sea. In the year 1665, twenty-two tenements had been destroyed under the cliff. At that period there still remained under the cliff 113 tenements, the whole of which were overwhelmed in 1703 and 1705. No traces of the ancient town are now perceptible; yet there is evidence that the sea has merely resumed its ancient position at the base of the cliffs, the site of the old town having been merely a beach abandoned by the ocean for ages.

* Mantell, *Geology of Sussex*, p. 293.

Hampshire—Isle of Wight.—It would be endless to allude to all the localities on the Sussex and Hampshire coasts where the land has given way; but I may point out the relation which the geological structure of the Isle of Wight bears to its present shape, as attesting that the coast owes its outline to the continued action of the sea. Through the middle of the island runs a high ridge of chalk strata, in a vertical position, and in a direction east and west. This chalk forms the projecting promontory of Culver Cliff on the east, and of the Needles on the west; while Sandown Bay on the one side, and Compton Bay on the other, have been hollowed out of the softer sands and argillaceous strata, which are inferior to the chalk.

The same phenomena are repeated in the Isle of Purbeck, where the line of vertical chalk forms the projecting promontory of Handfast Point; and Swanage Bay marks the deep excavation made by the waves in the softer strata, corresponding to those of Sandown Bay.

Hurst Castle Bank.—The entrance of the Channel called the Solent is becoming broader by the waste of the cliffs in Colwell Bay; it is crossed for more than two thirds of its width by the shingle bank of Hurst Castle, which is about seventy yards broad and twelve feet high, presenting an inclined plane to the west. This singular bar consists of a bed of rounded chalk flints, resting on a submarine argillaceous base. The flints and a few other pebbles, intermixed, are exclusively derived from the waste of Hordwell, and other cliffs to the westward, where tertiary strata, capped with a covering of chalk flints, from five to fifty feet thick, are rapidly undermined.

Storm of Nov. 1824.—In the great storm of November, 1824, this bank of shingle was moved bodily forwards for forty yards towards the north-east; and certain piles which served to mark the boundaries of two manors were found, after the storm, on the opposite side of the bar. At the same time many acres of pasture land were covered by shingle, on the farm of Westover, near Lymington.

The cliffs between Hurst Shingle Bar and the mouth of the Stour and Avon are undermined continually. Within the memory of persons now living, it has been necessary thrice to remove the coast-road farther inland. The tradition, therefore, is probably true, that the church of Hordwell was once in the middle of that parish, although now very near the sea. The promontory of Christ Church Head gives way slowly. It is the only point between Lymington and Poole Harbour, in Dorsetshire, where any hard stony masses occur in the cliffs. Five layers of large ferruginous concretions, somewhat like the septaria of the London clay, have occasioned a resistance at this point, to which we may ascribe this headland. In the mean time, the waves have cut deeply into the soft sands and loam of Poole Bay; and, after severe frosts, great land-slips take place, which, by degrees, become enlarged into narrow ravines, or chines, as they are called, with vertical sides. One of these chines, near Boscomb, has been deepened twenty feet within a few years. At the head of each there is a spring, the waters of which have been chiefly instrumental in producing these narrow excavations, which are sometimes from one hundred to 150 feet deep.

Isle of Portland.—The peninsulas of Purbeck and

Portland are continually wasting away. In the latter, the soft argillaceous substratum (Kimmeridge clay) hastens the dilapidation of the superincumbent mass of limestone.

In 1665 the cliffs adjoining the principal quarries in Portland gave way to the extent of one hundred yards, and fell into the sea; and in December, 1734, a slide to the extent of 150 yards occurred on the east side of the isle, by which several skeletons, buried between slabs of stone, were discovered. But a much more memorable occurrence of this nature, in 1792, occasioned probably by the undermining of the cliffs, is thus described in Hutchins's History of Dorsetshire:—"Early in the morning the road was observed to crack: this continued increasing, and before two o'clock the ground had sunk several feet, and was in one continued motion, but attended with no other noise than what was occasioned by the separation of the roots and brambles, and now and then a falling rock. At night it seemed to stop a little, but soon moved again; and before morning, the ground, from the top of the cliff to the water-side, had sunk in some places fifty feet perpendicular. The extent of ground that moved was about *a mile and a quarter* from north to south, and six hundred yards from east to west."

Formation of the Chesil Bank.—Portland is connected with the main land by the Chesil Bank, a ridge of shingle about seventeen miles in length, and, in most places, nearly a quarter of a mile in breadth. The pebbles forming this immense barrier are chiefly of limestone; but there are many of quartz, jasper, chert, and other substances, all loosely thrown together. What is singular, they gradually diminish in size, from west to east—from the Portland end of the

bank to that which attaches to the main land. The formation of this bar may probably be ascribed, like that of Hurst Castle, to a meeting of tides, or to a great eddy between the peninsula and the land. We have seen that slight obstructions in the course of the Ganges will cause, in the course of a man's life, islands many times larger than the whole of Portland, and which, in some cases, consist of a column of earth more than one hundred feet deep. In like manner we may expect the slightest impediment in the course of that tidal wave, which is sweeping away annually large tracts of our coast, to give rise to banks of sand and shingle many miles in length, if the transported materials be intercepted in their way to those submarine receptacles whither they are borne by the current. The gradual diminution in the size of the gravel as we proceed eastward might probably admit of explanation, if the velocity of the tide or eddy at different points was ascertained; the rolled masses thrown up being largest where the motion of the water is most violent, or where they are deposited at the least distance from the rocks from which they were detached. The storm of 1824 burst over this bar with great fury, and the village of Chesilton, built upon the southern extremity of the bank, was overwhelmed, with many of the inhabitants.* The fun-

* This same storm carried away part of the Breakwater, at Plymouth, and huge masses of rock were lifted from the bottom of the weather side, and rolled fairly to the top of the pile. It was in the same month, and also during a spring-tide, that a great flood is mentioned on the coasts of England, in the year 1099. Florence of Worcester says, "On the third day of the nones of Nov. 1099, the sea came out upon the shore, and buried towns and men very many, and oxen and sheep innumerable." Also

damental rocks whereon the shingle rests are found at the depth of a few yards only below the level of the sea.

Dorsetshire — Devonshire — Cornwall. — At Lyme Regis, in Dorsetshire, the “Church Cliffs,” as they are called, consisting of lias about one hundred feet in height, have gradually fallen away, at the rate of one yard a year, since 1800.* The cliffs of Devonshire and Cornwall, which are chiefly composed of hard rocks, decay less rapidly. Near Penzance, in Cornwall, there is a projecting tongue of land, called the “Green,” formed of granitic sand, from which more than thirty acres of pasture land have been gradually swept away in the course of the last two or three centuries.† It is also said that St. Michael’s Mount, now an insular rock, was formerly situated in a wood several miles from the sea; and its old Cornish name, according to Carew, signifies the Hoare Rock in the Wood. Between the Mount and Newlyn there is seen under the sand black vegetable mould, full of hazel nuts, and the branches, leaves, roots, and trunks, of forest trees, all of indigenous species. This vegetable stratum has been traced seaward as far as the ebb permits, and seems to indicate some ancient estuary on that shore.

the Saxon Chronicle, already cited for the year 1099, “This year, eke on St. Martin’s mass day, the 11th of Novembre, sprung up so much of the sea flood, and so myckle harm did, as no man minded that it ever afore did, and there was the ylk day a new moon.”

* This ground was measured by Dr. Carpenter of Lyme, in 1800, and again in 1829, as I am informed by Miss Mary Anning of Lyme.

† Boase, Trans. Royal Geol. Soc. of Cornwall, vol. ii. p. 129.

Tradition of loss of land in Cornwall. — The oldest historians mention a celebrated tradition in Cornwall, of the submersion of the Lionnesse, a country which formerly stretched from the Land's End to the Scilly Islands. The tract, if it existed, must have been thirty miles in length, and perhaps ten in breadth. The land now remaining on either side is from two hundred to three hundred feet high; the intervening sea about three hundred feet deep. Although there is no evidence for this romantic tale, it probably originated in some catastrophe occasioned by former inroads of the Atlantic upon this exposed coast.*

West coast of England. — Having now laid before the reader an ample body of proofs of the destructive operations of tides and currents on our eastern and southern shores, it will be unnecessary to enter into details of changes on the western coast, for they present merely a repetition of the same phenomena, and in general on an inferior scale. On the borders of the estuary of the Severn the flats of Somersetshire and Gloucestershire have received enormous accessions, while, on the other hand, submarine forests on the coast of Cheshire and Lancashire indicate the overflowing of alluvial tracts. Since the year 1764, the coast of Cheshire between the rivers Mersey and Dee has lost many hundred yards, and some affirm more than half a mile, by the advance of the sea upon abrupt cliffs of red clay and marls. Within the period above mentioned several light-houses have been successively abandoned.† There are tra-

* Boase, Trans. Royal Geol. Soc. of Cornwall, vol. ii. p. 190.

† Stevenson, Jameson's Ed. new Phil. Journ. No. 8. p. 386.

ditions in Pembrokeshire * and Cardiganshire † of far greater losses of territory than that which the Lionnesse tale of Cornwall pretends to commemorate. They are all important, as demonstrating that the earliest inhabitants were familiar with the phenomenon of incursions of the sea.

Loss of land on the coast of France.—The French coast, particularly that of Brittany, where the tides rise to an extraordinary height, is the constant prey of the waves. In the ninth century many villages and woods are reported to have been carried away, the coast undergoing great change whereby the hill of St. Michael was detached from the mainland. The parish of Bourgneuf, and several others in that neighbourhood, were overflowed in the year 1500. In 1735, during a great storm, the ruins of Palnel were seen uncovered in the sea.‡ A romantic tradition, moreover, has descended from the fabulous ages of the destruction of the south-western part of Brittany, whence we may probably infer some great inroad of the sea at a remote period. §

* Camden, who cites Gyraldus, also Ray, "On the Deluge," Phys. Theol. p. 228.

† Meyrick's Cardigan.

‡ Hoff, Geschichte, &c. vol. i. p. 49.

§ Ibid. p. 48.

END OF THE FIRST VOLUME.

LONDON :
Printed by A. SPOTTISWOODS,
New-Street-Square.

